

Real Exchange Rate Volatility in the Long-run Growth Process

Simon Shui-Ming Wan

Nuffield College, University of Oxford

Trinity Term 2014

Submitted for degree of Doctor of Philosophy in Economics

Abstract

Real Exchange Rate Volatility in the Long-run Growth Process

by Simon Shui-Ming Wan¹

Nuffield College, University of Oxford

Submitted for degree of Doctor of Philosophy in Economics

Trinity Term 2014

The objective of this thesis is to examine real exchange rate volatility, with a particular focus on investigating the causes of exchange rate jumps. While the predominant approach in the literature is to examine the interaction between nominal rigidities and nominal shocks, this thesis examines the volatility that arises from real rigidities and shocks. Trying to better understand the transmission of real shocks to the exchange rate is a worthwhile task, given the substantial evidence that these shocks and rigidities are important for explaining other economic fluctuations.

This thesis develops theoretical models that examine the contributions of specific real rigidities to exchange rate volatility. Chapter 1 introduces our baseline specification - a frictionless model, with the exception of capital adjustment costs. This baseline generates very mild exchange rate fluctuations. Additional rigidities are required to generate volatility of the magnitude that is typically observed. Chapter 2 finds that introducing imperfect asset substitutability - specifically, home asset bias - goes a little towards achieving this. When investors are biased, the exchange rate must adjust by more to equilibrate asset markets. This greater burden of adjustment on the exchange rate along the short run path typically translates to larger jumps after shocks. Similarly, Chapter 3 shows that augmenting the baseline with banks and financial frictions raises exchange rate volatility. The key point is that, in the presence of financial frictions, there is a risk premium that widens after negative shocks, increasing the required adjustment of the exchange rate. A fourth chapter extends Chapter 3 and shows that unconventional credit policy, while beneficial in some respects, nonetheless entails non-trivial costs because it invites moral hazard by encouraging banks to be more highly leveraged, which increases exchange rate and consumption volatility.

So, the overall message is that, in the presence of plausible real frictions - including (i) capital adjustment costs, (ii) imperfect asset substitutability, and (iii) financial frictions - real shocks can generate a plausibly significant degree of real exchange rate volatility. This thus posits an additional explanation of exchange rate jumps that complements the predominantly monetary literature.

¹Main Email: simon.wan@economics.ox.ac.uk

Secondary Email: ssmwan@gmail.com

Phone: +44 (0) 7748 207 268

Acknowledgements

First and foremost, I owe an immense debt of gratitude to my supervisor, David Vines, whose guidance and advice have been invaluable in developing this project from its earliest stages to its final form. Whether in his office in Oxford or when talking over Skype when he is in Australia and I am in the UK (or *vice versa*), his comments and corrections have always been incredibly astute and helpful.

Also deserving of an important mention is Paul Luk, whose knowledge of the literature and the more technical aspects of macroeconomic analysis I have benefited from greatly.

I would like to thank my college adviser Bent Nielsen for providing useful advice on the research process and James Forder for offering me the opportunity to teach undergraduates alongside my research, which has proven to be a valuable experience.

I would also like to thank, among others, Kubilay Ozturk, Tim Willems, Sebastien Walker, Pierre-Olivier Beffy, and participants at two departmental seminars, all of whose comments have improved this project immeasurably.

Financial assistance from the Clarendon Fund and Nuffield College is gratefully acknowledged, as is assistance from the Department of Economics, which allowed me to participate in the Royal Economic Society's Easter School.

Finally, I would like to thank an anonymous referee for the *International Economic Journal* for useful comments regarding a paper, based on Chapter 3, which is currently undergoing revision and resubmission.

Word count

Approximately 90,000 words (313 pages $\times$ 290 words on typical page)

Contents

Introduction	1
Chapter 1: Understanding exchange rate jumps — a baseline model	28
Chapter 2: Portfolio bias and exchange rate adjustment	86
Chapter 3: Financial frictions, risk premia, and exchange rate volatility	173
Chapter 4: Credit policy, exchange rate volatility, and moral hazard	267
Conclusion	307

Introduction

This thesis consists of this Introduction, four Chapters, and a brief Conclusion. The discrete Chapters are reasonably self-contained papers that share a common theme, a focus on exchange rate volatility. Hence each Chapter can be understood without specific reference to this Introduction. So, in this Introduction, we take the opportunity to provide some very general commentary on the thesis as a whole, rather than on the specific elements of the models.

Specifically, we briefly discuss the general objective and motivation for this thesis, before mapping out the relation of the thesis to the literature and how we depart from the existing models. We then outline a basic analytical framework which is used commonly in each of the Chapters for discussing exchange rate determination. We conclude with a brief preview of each Chapter.

1 Objective and motivation

The objective of this thesis is to understand the theoretical drivers of real exchange rate determination and, in particular, the causes of rapid jumps in real exchange rates. Understanding exchange rate dynamics is important because exchange rate fluctuations affect financial and consumption behaviour and thus have significant welfare implications. Furthermore, within a country, exchange rate fluctuations affect the allocation of resources between the tradeable and non-tradeable sectors and hence influence the underlying structure of the production side of the economy. Not only that, across countries, exchange rate fluctuations can affect patterns in goods trade and capital flows and hence the overall behaviour of the global economy.

We can illustrate the phenomenon we are interested in investigating. Figure 1 summar-

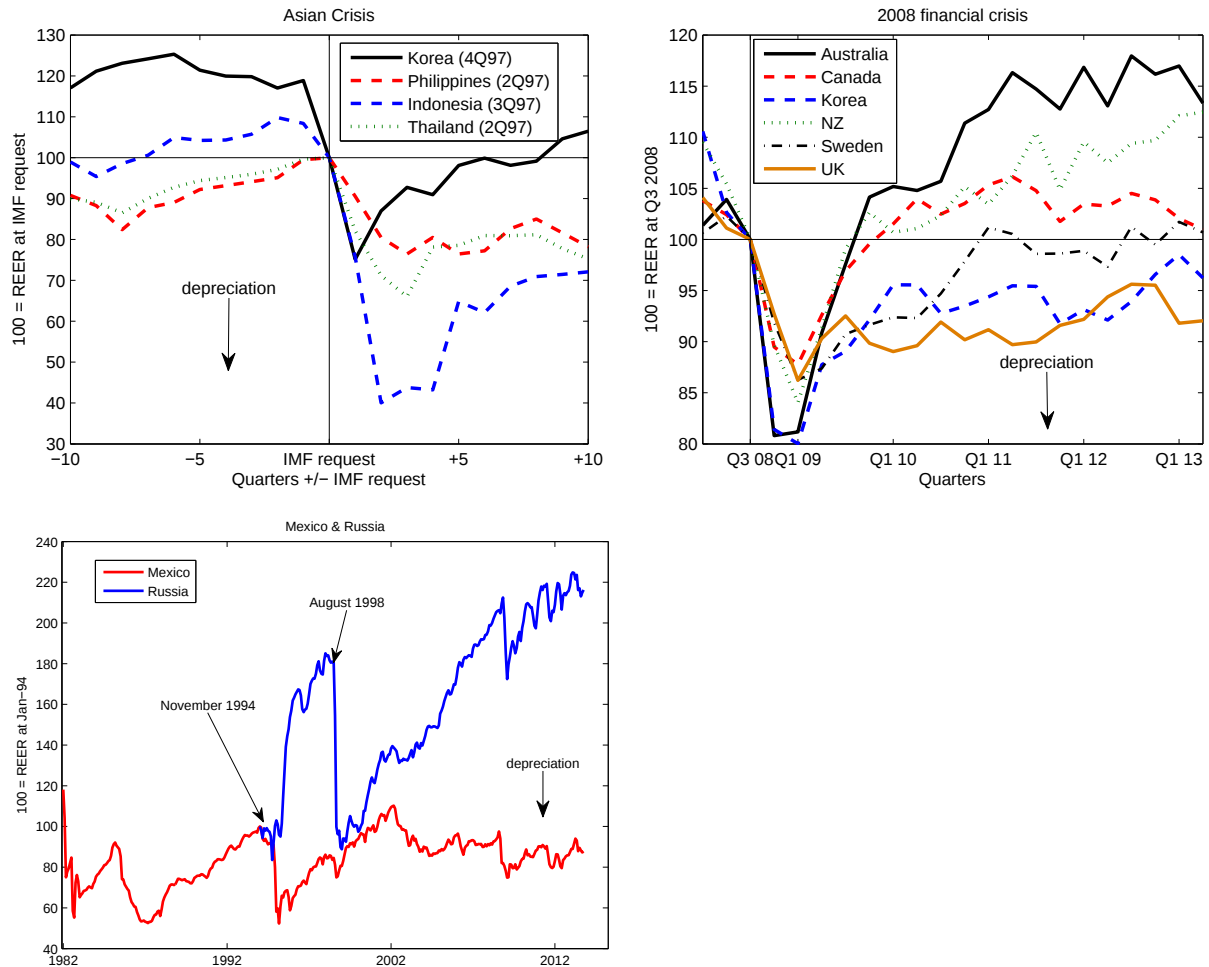
ises the motivation for this thesis. It charts real effective exchange rates from recent historical episodes: the Asian Crisis, the 2008 financial crisis, and two balance of payments crises in Mexico and Russia¹.

From inspection of figure 1, it is clear that exchange rates can experience rapid jumps (in this figure the jumps are depreciations but our focus is symmetric in both directions). For instance, in the space of the third quarter of 2008, Australia's real exchange rate depreciated by nearly 20%. Our aim in this thesis is to better understand *some* of the possible causes of these sharp changes in currency values. Furthermore, we observe from figure 1 that, after the initial jump, the exchange rates gradually appreciate and, several periods after the initial shock, have approached or surpassed their initial levels. To take Australia's example again, after five quarters the real exchange rate had appreciated by 5% relative to its pre-fall level. As we will show, this subsequent gradual adjustment of the exchange rate after the initial jump plays a significant role in explaining how the jumps themselves arise.

Other examples we could have pointed to include other Latin American balance of payments crises (the devaluation of the Brazilian real in 1999) and the pound sterling upon leaving the Exchange Rate Mechanism in 1992. The examples we have just listed are only the very notable episodes of large changes in exchange rates. They do not even include the moderate (but historically unmemorable) movements in exchange rates that can accompany long-run structural or large cyclical changes in an economy. For instance, very recently, currencies of many emerging markets have come under intense pressure due to the tapering of the Federal Reserve's quantitative easing programme: in the third quarter of 2013 and in real effective (trade-weighted) terms, the Indian

¹REERs are indexed to levels at the beginning of crises: for the Asian Crisis, this is the quarter when countries requested IMF assistance. For the 2008 financial crisis, this is the third quarter of 2008. While the Great Recession can be traced to the US housing decline in 2006-7, the wider financial crisis only materialised in the latter half of 2008 - the fall of Lehman Brothers in September 2008 is representative of this.

Figure 1: Rapid jumps of the real exchange rate



rupee fell by 5%, the Turkish lira by 6%, and the Indonesian rupiah by 10%².

To be clear, we do not claim that the theoretical models in this thesis explain these episodes in full. In Chapters 2 and 3 we show that the results of the models developed there can be very roughly mapped to actual historical episodes but we hesitate to make any conclusive claims about our models in relation to the data because we do not perform econometric analysis as part of this thesis. We only mention these examples to illustrate that rapid and sizeable movements in exchange rates are not uncommon

²Bank of International Settlements

occurrences. Developing a better understanding of them is thus a worthwhile task. And the task we confine ourselves to in this thesis is to develop a richer *theoretical* understanding of how exchange rates respond to shocks and why the effect on exchange rates can be magnified to such an extent that sharp changes in their value occur.

2 Exchange rate determination in the literature

In the following two sections, we discuss how this thesis relates to the literature. Each Chapter contains a literature review detailing how that Chapter's method and results relate to the existing models. Hence we leave a discussion of specific details to the reviews in the Chapters themselves. In the current section, we simply review the literature related to the common theme of the thesis as a whole, exchange rate determination.

The open macroeconomic literature on exchange rate determination is dominated by a body of work that shares the following features. Nominal prices are sticky and inflexible in the short run. Purchasing power parity holds in the long run. The nominal exchange rate, defined as the relative price of two currencies, obeys the uncovered interest parity condition. The impact of an exogenous shock to monetary policy is examined.

2.1 Dornbusch (1976)

Dornbusch (1976) is a seminal and early representative example of this literature. Dornbusch's main result is that, in response to a persistent shock to the money supply, the exchange rate initially overshoots its long run level. This overshooting is caused by differential speeds of adjustment in asset and goods markets.

Suppose the money supply rises permanently. At the new long-run equilibrium, the higher quantity of money bids up the domestic price level (which causes the home

nominal exchange rate to depreciate) until the point where the rise in the money supply is offset and the goods market returns to equilibrium, given the fixed level of output in the model. However, in the short run, prices are assumed to be sticky and slow to adjust. This means that, in the short run, domestic real money balances rise, causing real interest rates to fall and so home bonds become less attractive relative to foreign bonds. In order to bring asset markets back to equilibrium, the exchange rate appreciates along the adjustment path so that the common currency returns on home and foreign bonds are equalised. If the long run level of the exchange rate is depreciated, then, in order to appreciate in the short run, the exchange rate must initially depreciate so much that it overshoots its long run level.

What is occurring is that, because home and foreign bonds are treated as perfect substitutes *ex ante* and there are no frictions in asset markets, investors wish to substitute out of holding home bonds when the shock hits. Financial outflows occur and the exchange rate depreciates until the home currency is so under-valued that investors are willing to stop decumulating home bonds. This is the point where the subsequent upward movement of the exchange rate is sufficient to equalise the common currency returns on home and foreign bonds. The outflows stop, inflows resume and the exchange rate then gradually appreciates. In the long run, as prices adjust upwards, real money balances fall and the real interest rate rises, closing the gap between the absolute returns on home and foreign bonds.

Hence Dornbusch (1976) develops a model of exchange rate determination and also uses this model to explain jumps in exchange rates - in this instance, overshooting of long run levels. As we discuss below, we borrow many insights from this paper, most notably the idea that exchange rate jumps arise from differential speeds of adjustment in different markets. Contemporary papers that use similar model features and focus on monetary shocks as the drivers of exchange rate volatility include Stockman (1980)

and Lucas (1982) (who, unlike Dornbusch, assumes that PPP holds in the short run as well).

2.2 Adding microfoundations — Obstfeld and Rogoff (1995) and beyond

The next major development in this literature was made by Obstfeld and Rogoff (1995). Their contribution was to nest the intuitive models typified by Dornbusch's in a microfounded framework. Specifically, consumption is modelled as the decision of an optimising representative household, which yields a standard Euler equation. As is now familiar in open economy models, aggregate consumption is modelled as a Dixit-Stiglitz constant elasticity of substitution index of home and foreign goods. Nominal prices are assumed to be predetermined one period in advance and are free to adjust after that first period. This implies that, after a shock to a nominal variable, the economy reaches its new steady state after exactly one period.

Obstfeld and Rogoff (1995) became the new baseline model in exchange rate determination. Lane (2001) documents the major additions to this new baseline. These include: modelling nominal rigidity using Calvo pricing in order to endogenise price stickiness as the result of firm price-setting behaviour; a fuller specification of production technologies; modelling monetary policy as setting interest rates rather than money quantities.

These developments to Obstfeld and Rogoff have led to the emergence of a new class of conventional (small) open economy models typified by Gali and Monacelli (2005), Holmberg (2006), Justiniano and Preston (2010), and Senbeta (2011). The key common features include: a standard Euler equation to describe consumption behaviour; CES aggregation of home and foreign goods; Calvo pricing and hence a new Keynesian Phillips curve; the law of one price and the uncovered interest parity condition. The

implications for the exchange rate are qualitatively similar to those of Dornbusch. An expansionary monetary policy shock lowers real interest rates due to price rigidities, leading to an initial depreciation of the exchange rate, followed by a gradual appreciation back to steady state.

3 Turning to real shocks and rigidities

There is thus a strong tradition in the open macroeconomic literature of using *nominal rigidities* and *monetary shocks* to investigate exchange rate volatility. As discussed in section 1, we are also broadly interested in the same question of exchange rate determination. However, we take a slightly different approach. Instead of examining the exchange rate volatility that arises from the interaction between nominal rigidities and nominal (monetary policy) shocks, we focus on the volatility that may arise from the interaction between *real rigidities* and *real shocks*.

3.1 Our approach

Specifically, we focus on two main types of shocks: the first two Chapters consider shocks to aggregate productivity while the final two Chapters consider shocks to bank net worth, which can be interpreted as shocks to risk premia. The most basic real rigidity we consider is the slow adjustment of the capital stock. On top of this we then add imperfect asset substitutability between countries and financial frictions. The main substance of this thesis is concerned with understanding whether these real shocks, in the presence of these real frictions, can generate significant exchange rate volatility. Because we abstract from nominal rigidities, we treat the real exchange rate as the key variable of interest.

Abstracting from nominal rigidities is not new in the open macroeconomic literature. Blanchard, Giavazzi and Sa (2005) and Krugman (2007) do not assume nominal price stickiness. Moreover, some papers not only assume flexible prices, but also contain the types of real rigidities that we are interested in, such as the slow adjustment of capital, as introduced by the real business cycle (RBC) literature (Kydland and Prescott, 1982; Plosser, 1989). Examples include Meredith (2007), Ghironi, Lee and Rebucci (2009), Tille and van Wincoop (2010), Heathcote and Perri (2013), and Sa and Viani (2013). This thesis can be interpreted as following in this particular strand of literature that examines open economies in flexible price models with real rigidities. However, the examples cited above, while still describing open economies, do not examine the issue of exchange rate determination. This thesis can also be broadly interpreted as building a bridge between this open RBC methodology and the aims and objectives of the monetary models that explicitly address exchange rate determination.

3.2 Rationale for our approach

Why do we take this different approach? There are two main reasons. First, our area of focus is arguably different. The nominal rigidity literature is typically concerned with exchange rate volatility at the business cycle interval and hence modelling sticky prices and monetary shocks is appropriate. On the other hand, as will become apparent in the Chapters, we are more interested in how exchange rates respond to persistent shocks to the economy whose effects do not wash out until the medium or long run. In this case, rigid prices may play a smaller role in the dynamic adjustment of the economy and shocks to monetary policy will not be as relevant as shocks to productivity.

For instance, the Australian dollar experienced a substantial and persistent appreci-

ation from 2001 to 2008³ due to (among other reasons) a surge in demand for export commodities stemming from the accelerating secular growth of emerging markets. This arguably represents a structural change rather than a cyclical swing in demand. Similarly, now that commodities demand is expected to persistently decline due to secular changes in infrastructure spending in these same emerging markets, the Australian economy is likely to undergo another structural change (the consumption-investment mix and the sectoral allocation of capital are likely to be heavily affected, given that mining capital expenditure constitutes around 8% of Australian GDP⁴) and hence the real exchange rate is likely to respond to this change. Nominal rigidities in prices or wages do not appear to play a significant role in this narrative.

Certainly, there is evidence that nominal shocks cannot account for all real exchange rate movements. Chari, Kehoe and McGrattan (2002) find that in order for monetary shocks to generate the same real exchange rate volatility as in the data, nominal prices have to be predetermined for at least a year and agents must exhibit an equally implausibly high degree of risk aversion. Similarly, Crucini, Shintani and Tsuruga (2013) find that nominal shocks account for less than a quarter of the forecast error variance of the real exchange rate at a 3-month horizon and this dissipates to less than 15% at the 12-month horizon.

The second reason for our approach is that the literature suggests that real shocks and rigidities are important for explaining economic fluctuations and so it is worthwhile to try to better understand the transmission of real shocks to the exchange rate. There is some evidence that productivity shocks are significant, even at business cycle frequencies. Using the business cycle accounting approach of Chari, Kehoe and McGrattan (2007), Chakraborty (2009) finds that the “efficiency wedge” (which can be interpreted

³A 40% rise in the real effective exchange rate (Bank of International Settlements)

⁴Speech by RBA Assistant Governor Christopher Kent, “The Outlook for Business Investment in Australia”, 10 April 2013.

as exogenous productivity) can explain a large proportion of fluctuations (e.g. 55% of changes in hours worked) in Japan over the 1980s-1990s. Hayashi and Prescott (2002) go even further and claim that exogenous productivity shocks can explain almost all economic variations in Japan over the 1990s.

In emerging markets, Chakraborty and Otsu (2013) show that, over the 2000s, the “efficiency wedge” accounted for over 98% of output variation in Brazil and Russia, around 43% in India, and 30% in China. Furthermore, Peersman and Straub (2004) find that, in the Euro area, technology shocks account for around a quarter of fluctuations in hours worked from 1982 to 2002. Their conclusion is that “the results are in favour of the RBC paradigm”: a flexible price model in which real technology shocks are transmitted via real rigidities. Finally, recall that the other type of real shock we consider is a shock to the risk premium. Amano and Shukayev (2012) find that these types of shocks are critical for DSGE models to quantitatively explain business cycle properties. It is worth noting that Meese and Rogoff (1988) argued that focusing on monetary shocks in exchange rate modelling may be a misspecification because shocks are predominantly real.

3.3 How important are real shocks?

What is the potential quantitative effect of these real shocks on the real exchange rate? A very rough way of framing this question is to ask what is the quantitative effect of technology shocks on the real interest rate. This is because if we make the very weak assumption that capital generally flows to where the real returns are higher, then real exchange rates will move with real interest rates. Baxter (1994), using low-frequency real data, finds support for a simple long-run relationship between the real interest rate and real exchange rate. The estimates of the impact of technology shocks on

real interest rates vary widely. On the upper end of the scale, Wang and Wen (2007), replicating the reduced form VAR estimation of Basu, Fernald and Kimball (2006) for the US, find that an aggregate technology shock (one standard deviation) raises the real interest rate by around 8 percentage points. Other estimates are far more muted. Peersman and Straub (2004) find that a technology shock in the Euro area raises the real interest rate by around 0.9 points.

Nonetheless, this points to a moderate variability of the real exchange rate caused by productivity shocks (especially if the interest rate differential persists). Taking the lower estimate of Peersman and Straub (2004), this would imply (very roughly speaking) a 1 percentage point depreciation of the real exchange rate for every quarter that the shock persisted.

While several studies find that the marginal products of capital are equalised across countries because capital flows are not hindered by credit frictions (Caselli and Feyrer, 2007; Olufowote, 2012), the hypothesis of equalised real interest rates across countries is typically rejected (Mishkin, 1984). More specifically, Pigott (1993) finds that while dispersion in *covered* rates (that is, where exchange rate risk is hedged by forward contracts) is approximately zero, dispersion in *uncovered* real interest rates between developed countries is around 2% in the short run, and only washing out to 1.5% in the long run, suggesting that this differential persists due to real exchange rate volatility.

In summary, the models of this thesis examine real rigidities and real shocks in order to explain exchange rate volatility. This departs slightly from the existing convention of examining nominal (monetary) shocks in a system with nominal rigidities (price and wage stickiness). We take this approach because we are more interested in the medium to long run horizon and there is some suggestion from the empirical literature that real shocks are important for explaining fluctuations, even at business cycle intervals.

4 Guide to the reader

The first three sections of this Introduction set the general context for this thesis. In this section, we provide some notes that serve as a guide to the reader for the main Chapters.

4.1 A basic framework for presenting our results

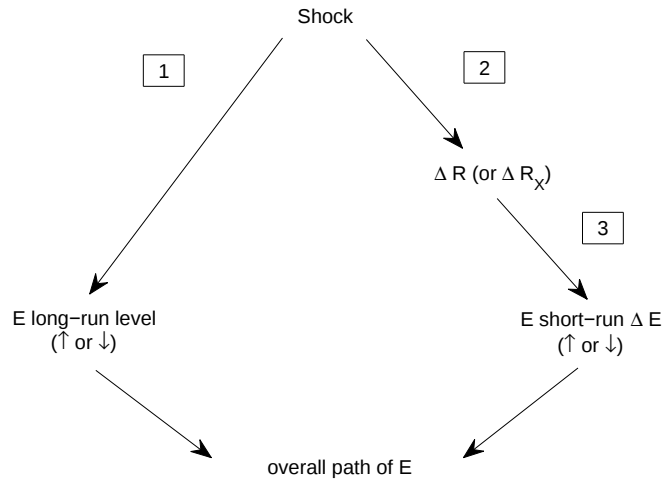
Here, we introduce a simple way in which we outline the key result in each Chapter. This is visualised in figure 2. This is simply an accounting framework that decomposes the effect of each shock we consider on the real exchange rate. The framework itself and its implications are not novel.

Consider the first arrow in figure 2. This represents the effect of the shock on the *long-run level* of the exchange rate at the new steady state. As we will see in Chapter 1, this relationship is typically pinned down by goods equilibrium conditions. For instance, in Dornbusch (1976), after a permanent rise in the domestic money supply, the new long-run level of the nominal exchange rate is depreciated (relative to the starting point) because the domestic price level rises.

Consider the second arrow in figure 2. This represents the effect of the shock on real interest rates. In Dornbusch, a rise in the money supply in the presence of price rigidities leads to a rise in real money balances, hence causing the real interest rate to fall. The third arrow represents the effect of the change in the real interest rate on the *short-run rate of change* of the exchange rate. In Dornbusch, because home and foreign bonds are treated as perfect substitutes *ex ante* and the return on home bonds falls, the exchange rate appreciates in the short run to compensate for this in equilibrium.

Together, the long-run level and short-run rate of change explain the overall path of the

Figure 2: Exchange rate determination

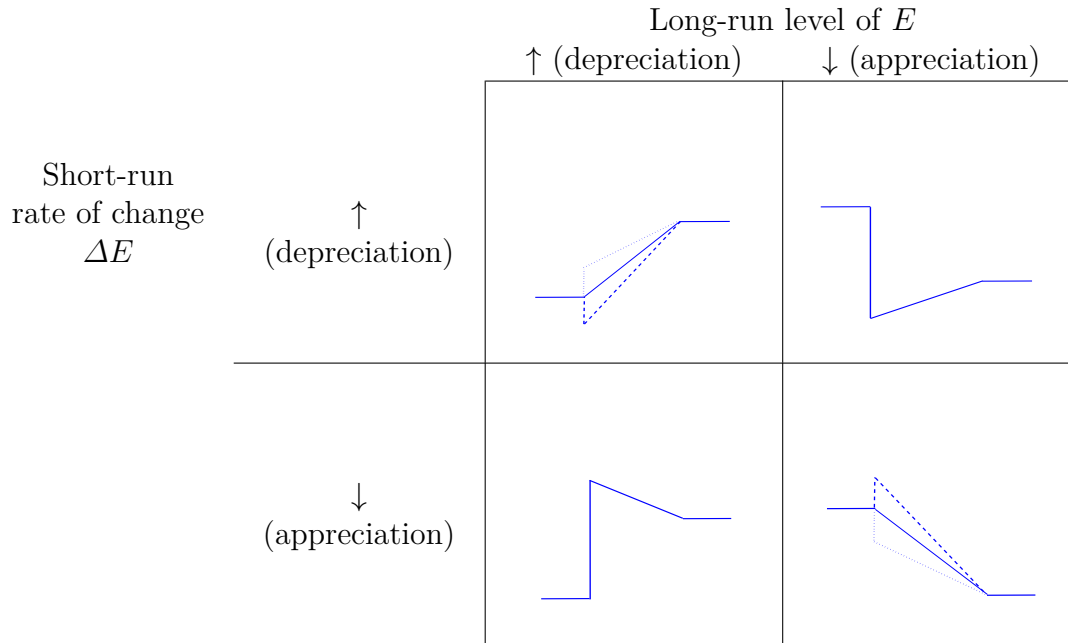


exchange rate. To summarise the Dornbusch result again, a depreciated long-run level of the exchange rate combined with a short-run appreciating rate of change implies that the exchange rate initially depreciates by such a large amount that it overshoots its long-run level. In the Chapters, we will use this basic schematic to break down the effect of each shock on the exchange rate.

Table 1 visualises (in a stylised linear manner) the possible paths of the exchange rate across time, given the combination of its long-run level and short-run rate of change (the first and third arrows in figure 2). Note that we define the real exchange rate as the price of foreign goods relative to home goods. An increase in the exchange rate denotes a depreciation for the home country.

In table 1, the Dornbusch result is represented in the lower left corner: a depreciated ($\uparrow$) long-run level and a short-run appreciation ($\downarrow$) imply the path shown - an overshooting depreciation followed by a gradual appreciation. Conversely, an appreciated long-run level with a short-run depreciation imply an overshooting appreciation followed by a gradual depreciation, as the top right corner shows. When the directions of both the

Table 1: Possible paths of the exchange rate



long-run level and short-run rate of change coincide (top left and bottom right corners), the path is more ambiguous and so the initial jump (if there is one) depends on the numerical parameterisation and other quantitative features of the model.

We explain this basic accounting framework in more detail in section 2 of Chapter 1.

4.2 Some caveats

We discuss some general caveats related to the thesis as a whole. Discussion of more specific caveats and possible extensions comes in the Chapters.

First, while many papers model the real exchange rate as the price of tradeable goods relative to non-tradeables, this thesis ignores the existence of a non-tradeable sector completely and instead defines the real exchange rate as the price of (homogeneous) foreign goods in terms of (homogeneous) home goods. Arguably, this is an over-simplification and a possible extension would be the inclusion of multiple production sectors.

However, to offer just one response to this possible critique, there is some suggestion in the literature that the prices of non-tradeable goods may not be important in determining real exchange rates. Chari, Kehoe and McGrattan (2002) find that the relative price of non-traded goods to traded goods accounts for only around 2% of the variance of the real exchange rate. This follows the result of Engel (1999), who found that the relative price of non-traded goods accounted for none of the variation in the US real exchange rate in 20 to 30 years of data and this finding is robust to five different measures of price levels. Parsley (2007) makes a similar finding regarding real exchange rates in East Asia. It may be possible to justify the absence of a non-tradeable sector in our thesis on this basis.

Second, in the first three Chapters, the models are solved using standard linear perturbation techniques after taking a log-linear approximation of the model. This is fairly standard practice in open economy macroeconomics. Examples of papers that take log-linear approximations of models include: Gali and Monacelli (2005), Justiniano and Preston (2010), Senbeta (2011), Obstfeld and Rogoff (1995), Sa and Viani (2013), Ghironi, Lee and Rebucci (2009), Engel and Matsumoto (2009), and Kuralbayeva and Vines (2009)⁵. Linearisation is a common technique. The problem, however, is that even though we consider small or temporary shocks in this thesis, we are also concerned with investigating jumps in exchange rates that may be large in size, and hence the model approximations may be inaccurate. So, an obvious extension to the thesis as a whole would be to apply a non-linear solution method to achieve more accurate results.

We make three arguments in defence of our choice of solution method. First, despite its shortcomings, log-linearisation is a simple technique that can yield intuitive solutions that are not purely numerical in nature. Second, as will become evident in Chapter

⁵We could add to this list the literature cited in Kose (2002): Ahearne (1997), Baxter and Crucini (1995), Correia, Neves and Rebelo (1995), Kouparitsas (1997), Schmitt-Grohe (1998), Senhadji (1998).

2, in the presence of a portfolio choice problem, log-linearisation may be a necessary technique in order to solve the model. Specifically, in order to solve for the optimal portfolio of agents, we apply the method of Devereux and Sutherland (2011), which necessitates taking a linear approximation of the model to describe dynamics. Third, log-linearisation may be accurate enough even though we are considering potentially large deviations from steady state. Dotsey and Mao (1992) find that log-linearisation is highly accurate for closed economy models. In open economy models, as Kose (2002) notes, the main element not captured by log-linearisation is precautionary saving on part of risk averse agents and it is not clear how great the effect of this is.

Finally, this is not so much a caveat but a note to the reader. When we explain the results in each Chapter (specifically, why the exchange rate behaves the way it does), we typically provide both a *reduced form* and a *structural form* explanation for the results. The reduced form description explains exchange rate dynamics by asking how the exchange rate needs to adjust in order to satisfy equilibrium conditions in the model. On the other hand, the structural form description explains dynamics by asking what incentives lead agents to act in such a way that causes the exchange rate to move the way it does.

To take the Dornbusch overshooting example again, the reduced form explanation is that, because in the long run the exchange rate is depreciated, but in the short run the exchange rate has to appreciate in order to equilibrate asset markets (by equalising the common currency returns on home and foreign bonds), the exchange rate must initially overshoot its long run level. The structural form explanation is that, because the return on home bonds falls, investors substitute out of home bonds into foreign bonds, causing financial outflows and the exchange rate to depreciate until it is so under-valued that investors are once again willing to hold onto home bonds. We include both explanations for completeness.

5 Preview of Results

So far we have only described very general aspects of the thesis. Here we provide a brief preview of the specific results of the Chapters that follow.

5.1 Chapter 1

This thesis begins by presenting a baseline (and mainly frictionless) model of exchange rate determination. This is a very simple model of a small open economy with basic RBC features such as Cobb Douglas production and a capital stock. Nominal prices are flexible and the only rigidity is the slow adjustment of capital. International asset markets are frictionless and represented by the UIP condition. This is the simplest baseline specification against which the other models in this thesis can be compared. The purpose of this Chapter is two-fold.

First, we explain in greater detail the method of accounting for exchange rate movements that we outlined above in figure 2 and table 1. Essentially, goods equilibrium conditions pin down the new long run level of the exchange rate after a shock while asset market equilibrium conditions determine the per-period adjustment of the exchange rate in the short run. The initial behaviour of the exchange rate then depends on the relative sizes and directions of these two effects. For illustration, if both the long run and short run effects are in the direction of appreciation (as represented in the bottom right corner of table 1), then (i) whether the exchange rate initially jumps, and (ii) the size and direction of this jump, will depend on whether the short run effect is larger than the long run effect. This simply elaborates on the accounting method within which we will frame our results.

The second and main purpose of this Chapter is then to apply this framework to

the simple model we set up and explain how the rigid adjustment of capital leads to volatility of the exchange rate. Suppose there is a permanent negative productivity shock. Consider the first arrow in figure 2. The supply of home goods permanently falls and so in the long run the exchange rate converges on an appreciated level in order to clear the goods market (the relative price of home goods rises). Consider the second arrow in figure 2. The home stock of capital becomes less productive. The real return on home bonds thus falls and investors wish to hold foreign bonds instead. The third arrow in figure 2 follows from the second. In order to equilibrate the asset market, the common currency return on home bonds must rise to match that of foreign bonds. This implies that the exchange rate must appreciate along the adjustment path. As the bottom right corner of table 1 shows, if the exchange rate appreciates both in the long and short run, it initially undershoots and the size and direction of the jump (if there is one) depend on the relative sizes of the long and short run effects.

The rigid evolution of capital is crucial because if capital could adjust to its new long run level immediately, then the marginal product of capital would remain constant (since the marginal product of each unit of capital rises as the total capital stock declines) and the real return on home bonds would be constant. This narrative thus shares some similarities with that in Dornbusch, except that while in his model the initial fall in the real interest rate is caused by a rise in the money supply combined with rigid prices, in ours this fall is caused by negative productivity shocks combined with the initial rigidity of the capital stock.

However, in a sensibly calibrated model, and in the absence of any other frictions, this channel only generates a small degree of exchange rate volatility. This is because, if there is an endogenous price of capital (Tobin's Q), this price of capital falls sharply in the event of a negative shock, relieving much of the burden of adjustment on the interest rate. As a result, the real return on home bonds only falls moderately and hence

the exchange rate only fluctuates mildly as well (when compared with the responses of other variables like output and consumption). Other features need to be present in the model for real shocks and rigidities to generate a significant degree of exchange rate volatility.

5.2 Chapter 2

We then augment the analysis of Chapter 1 by introducing imperfect substitutability between home and foreign bonds. This Chapter is motivated by the apparent failure of the UIP condition in the empirical literature, which is consistent with the finding of the previous Chapter that a frictionless model with UIP generates very low levels of volatility. We introduce imperfect asset substitutability by positing that investors are biased in favour of holding home assets over foreign assets *ceteris paribus*. This Chapter has two main findings.

First, we show that a very simple model can predict a plausible degree of home asset bias, replicating a key stylised fact of international asset markets. This follows an extensive theoretical literature that makes the same finding (Palacios-Huerta, 2001; Coeurdacier, Kollmann and Martin, 2009 and 2010; Engel and Matsumoto 2009; Heathcote and Perri, 2013). Arguably, we arrive at this result with a much simpler model and with very parsimonious assumptions.

The main finding is that this portfolio bias augments the volatility of the exchange rate after productivity shocks, compared to the baseline case of perfect substitutability (UIP). The reason for this is straightforward. After a negative productivity shock (as we considered in Chapter 1), home assets become relatively scarcer and so even though the real return at home falls, biased investors wish to hold more home assets, causing financial inflows and an initial appreciation of the exchange rate. Only when the home

currency is sufficiently over-valued are investors willing to stop flooding to the home asset. This is the point where the subsequent depreciation of the exchange rate to its long run level makes the home asset unattractive enough that even biased investors no longer wish to accumulate more of it.

So, in the short run, the exchange rate depreciates along the adjustment path after a negative shock to productivity. As in Chapter 1, the long run level of the exchange rate is appreciated after this shock (since the supply of home goods declines). Hence, as the top right panel of table 1 shows, an appreciated long run level and a depreciated short run adjustment imply an initial overshooting of the exchange rate. And overshooting then implies greater volatility than the mild undershooting that occurred under UIP (Chapter 1). This result overturns a key paper on imperfect asset substitutability by Blanchard, Giavazzi and Sa (2005) and we will show that this difference arises because we treat the capital stock as endogenous and time-varying, rather than fixed.

The “reduced” form explanation of this overshooting is a little more involved. The essential detail is that in steady state, home investors, because of their biased preferences, wish to hold a fixed fraction of their wealth greater than 50% in the home asset. The shock permanently lowers the quantity of outstanding home assets and so in equilibrium it must be the case that total home wealth falls. This fall in wealth comes about by a running down of net national savings through a current account deficit. In order to induce this deficit, the exchange rate becomes over-valued, relative to its long run level, along the adjustment path. Because the long run level of the exchange rate is also appreciated (the supply of home goods falls), then in order for the exchange rate to be over-valued relative to this appreciated level, it must initially overshoot.

Imperfect asset substitutability thus generates a higher and more plausible degree of exchange rate volatility and, furthermore, provides a reason as to why exchange rates move in the opposite direction to that predicted by UIP (when responding to the same

productivity shock).

5.3 Chapter 3

In Chapter 3, we extend the analysis of Chapter 1 further, by introducing financial frictions and a banking sector. This Chapter is motivated by the self-evident relevance of financial shocks in explaining economic fluctuations, made obvious by the 2008 crisis. The main result of this Chapter is that financial shocks in the presence of financial frictions augment the volatility of the exchange rate even more, giving rise to significant jumps. The shock is transmitted to the exchange rate via the risk premium. In the presence of financial frictions, lenders typically demand a non-negative risk premium from borrowers. Here, we suppose that the banking sector obtains funding from depositors who demand this premium.

Suppose there is a fall in the net worth of the home banking sector. Bank leverage immediately worsens and depositors demand a higher premium because the cost of potential default rises. In other words, the bank's return on its portfolio must rise relative to the foreign riskless rate (since depositors have the option of saving risklessly overseas). Suppose the foreign riskless rate does not fall, and the return on the bank's risky assets does not rise. In this case, the exchange rate must carry the burden of adjustment. The exchange rate must experience a very large short run appreciation that raises the foreign currency value of the bank's earnings. This then allows the bank to earn the required spread (above foreign riskless rates) that lenders demand. A very large short run appreciation (combined with a very small long run appreciation) thus implies a large initial depreciation, as the bottom right corner of table 1 illustrates. Intuitively, depositors withdraw from home banks and flood to safe-haven assets abroad, causing the exchange rate to fall until it is sufficiently under-valued to entice investors back to

domestic money markets. This is the point where the exchange rate is so depreciated that its subsequent expected per-period appreciation widens the spread between the home bank's earnings and the foreign riskless rate sufficiently to keep investors satisfied with funding domestic banks.

Contrary to the third generation currency crisis literature arising from the Asian Crisis (e.g. Cespedes, Chang and Velasco, 2004), our model suggests that a large currency mismatch on balance sheets is not necessary for a financial shock to generate a large fall in exchange rates. This is because a large rise in the risk premium can occur for reasons independent of the denomination of balance sheets.

5.4 Chapter 4

We conclude the thesis with a brief examination of the effect of unconventional policy in the presence of financial frictions. In the same spirit as Cespedes, Chang and Velasco (2012), we examine the effect of credit policies whereby authorities extend emergency loans to the goods-producing sector or to banks. Similar to these authors we find that both of these policies lead to higher output and investment. Furthermore, the policy of lending to banks is more effective in terms of raising output because for any unit of credit extended to banks, banks can lever up and extend more than one unit of credit to the goods-producing sector. However, lending to banks has non-trivial welfare costs because it encourages banks to be under-capitalised. Hence bank leverage is higher under this policy, which raises the volatility of key variables, including consumption and the exchange rate. We interpret this as indicative of the problem of moral hazard.

This thesis thus presents a unified message on a single theme: real exchange rate volatility. *Chapter 1* shows that a baseline (and mostly frictionless) model can generate

some exchange rate volatility due to the real rigidity implied by the slow adjustment of capital. However, the volatility under this model is fairly muted and exchange rate jumps are fairly small relative to the size of the shocks. *Chapter 2* shows that adding imperfect asset substitutability not only causes the exchange rate to move in the opposite direction to that predicted by UIP (in response to the same shock as simulated in *Chapter 1*), but also generates exchange rate overshooting rather than undershooting, hence implying a greater degree of volatility. *Chapter 3* shows that adding a financial friction and financial shocks augments exchange rate volatility even more. *Chapter 4* extends *Chapter 3* with a simple policy experiment.

This thesis thus proposes that certain real shocks and real rigidities can generate a substantial degree of exchange rate volatility and shows how real rigidities can produce sharp jumps in the exchange rate.

References

- [1] Ahearne, Alan G. 1997. Trade liberalization and capital accumulation in developing economies: a quantitative analysis. Working Paper, Carnegie Mellon University.
- [2] Amano, Robert & Malik Shukayev. 2012. Risk premium shocks and the zero bound on nominal interest rates. *Journal of Money, Credit and Banking* 44 (8): 1475—1505.
- [3] Basu, Susanto, John Fernald, & Miles Kimball. 2006. Are technology improvements contractionary?. *American Economic Review* 96 (5): 1418—1448.
- [4] Baxter, Marianne. 1994. Real exchange rates and real interest differentials: have we missed the business-cycle relationship?. *Journal of Monetary Economics* 33 (1): 5—37.
- [5] Baxter, Marianne & Mario Crucini. 1995. Business cycles and the asset structure of foreign trade. *International Economic Review* 36: 821—54.
- [6] Blanchard, Olivier, Francesco Giavazzi, & Filipa Sa. 2005. The US current account and the dollar. NBER Working Papers 11137. National Bureau of Economic Research.

-
- [7] Caselli, Francesco & James Feyrer. 2007. The marginal product of capital. *The Quarterly Journal of Economics* 122 (2): 535—568.
- [8] Cespedes, Luis F., Roberto Chang, & Andres Velasco. 2004. Balance sheets and exchange rate policy. *American Economic Review* 94 (4): 1183—93.
- [9] ———. 2012. Financial intermediation, exchange rates, and unconventional policy in an open economy. NBER Working Papers 18431. National Bureau of Economic Research.
- [10] Chakraborty, Suparna. 2009. The boom and the bust of the Japanese economy: a quantitative look at the period 1980-2000. *Japan and the World Economy* 21 (1): 116—131, January.
- [11] Chakraborty, Suparna & Otsu Keisuke. 2013. Business cycle accounting of the BRIC economies. *The B.E. Journal of Macroeconomics* 13 (1): 1—33, September.
- [12] Chari, Varadarajan V., Patrick J. Kehoe & Ellen R. McGrattan. 2002. Can sticky price models generate volatile and persistent real exchange rates?. *Review of Economic Studies* 69 (3): 533—63.
- [13] ———. 2007. Business cycle accounting. *Econometrica* 75 (3): 781—836.
- [14] Coeurdacier, Nicolas, Robert Kollmann, & Philippe Martin. 2009. International portfolios with supply, demand and redistributive shocks. In *NBER International Seminar on Macroeconomics 2007*, edited by Richard Clarida and Francesco Giavazzi. Chicago, Illinois: University of Chicago Press.
- [15] ———. 2010. International portfolios, capital accumulation and foreign asset dynamics. *Journal of International Economics* 80 (1): 100—12.
- [16] Correia, Isabel, Joao Neves, & Sergio Rebelo. 1995. Business cycles in a small open economy. *European Economic Review* 39: 1089—1113.
- [17] Crucini, Mario J., Mototsugu Shintani, & Takayuki Tsuruga. 2013. Do sticky prices increase real exchange rate volatility at the sector level?. *European Economic Review* 62: 58—72.
- [18] Devereux, Michael B., & Alan Sutherland. 2011. Country portfolios in open economy macro-models. *Journal of the European Economic Association* 9 (2): 337—69.
- [19] Dornbusch, Rudiger. 1976. Expectations and exchange rate dynamics. *Journal of Political Economy* 84 (6): 1161—76.
- [20] Dotsey, Michael & Ching-Sheng Mao. 1992. How well do linear approximation methods work? The production tax case. *Journal of Monetary Economics* 29: 25—58.

-
- [21] Engel, Charles. 1999. Accounting for US real exchange rate rate changes. *Journal of Political Economy* 107 (3): 507—38.
- [22] Engel, Charles & Akito Matsumoto. 2009. The international diversification puzzle when goods prices are sticky: it's really about exchange-rate hedging, not equity portfolios. *American Economic Journal: Macroeconomics* 1 (2): 155—88.
- [23] Gali, Jordi & Tommaso Monacelli. 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies* 72: 707—34.
- [24] Ghironi, Fabio, Jaewoo Lee, & Alessandro Rebucci. 2009. The valuation channel of external adjustment. IMF Working Paper WP/09/275. International Monetary Fund, Washington D.C., December 2009.
- [25] Hayashi, Fumio & Edward C. Prescott. 2002. The 1990s in Japan: a lost decade. *Review of Economic Dynamics* 5 (1): 206—35, January.
- [26] Heathcote, Jonathan & Fabrizio Perri. 2013. The international diversification puzzle is not as bad as you think. Working Papers 472, Innocenzo Gasparini Institute for Economic Research (IGIER), Bocconi University.
- [27] Holmberg, Karolina. 2006. Derivation and estimation of a new Keynesian Phillips curve in a small open economy. Sveriges Riksbank Working Paper Series No. 197, May.
- [28] Justiniano, Alejandro & Bruce Preston. 2010. Monetary policy and uncertainty in an empirical small open-economy model. *Journal of Applied Econometrics* 25 (1): 93—128
- [29] Kose, M. Ayhan. 2002. Explaining business cycles in small open economies: “How much do world prices matter?”. *Journal of International Economics* 56 (2): 299—327.
- [30] Kouparitsas, Michael. 1997. North-South business cycles. Working Paper Series, Macroeconomic Issues WP-97-05, Federal Reserve Bank of Chicago.
- [31] Krugman, Paul. 2007. Will there be a dollar crisis? *Economic Policy* 22: 435—67. CEPR, CES and MSH. July, 2007.
- [32] Kuralbayeva, Karlygash & David Vines. 2009. The process by which the dollar will fall: the effect of forward-looking consumers. CEPR Discussion Papers 7325. Centre for Economic Policy Research.
- [33] Kydland, Finn E. & Edward C. Prescott. 1982. Time to build and aggregate fluctuations. *Econometrica* 50 (6): 1345—70.
- [34] Lane, Philip R. 2001. The new open macroeconomics: a survey. *Journal of International Economics* 54 (2): 235—66.

-
- [35] Lucas, Robert E. 1982. Interest rates and currency prices in a two-country world. *Journal of Monetary Economics* 10 (3): 335—59.
- [36] Meese, Richard A. & Kenneth Rogoff. 1988. Was it real? The exchange rate-interest differential relation over the modern floating-rate period. *Journal of Finance* 43 (4): 933—48.
- [37] Meredith, Guy. 2007. Debt dynamics and global imbalances: some conventional views reconsidered. IMF Working Paper WP/07/4. International Monetary Fund, Washington, D.C., January 2007.
- [38] Mishkin, Frederic S. 1984. Are real interest rates equal across countries? An empirical investigation of international parity conditions. *The Journal of Finance* 39 (5): 1345—57.
- [39] Obstfeld, Maurice & Kenneth Rogoff. 1995. Exchange rate dynamics redux. *Journal of Political Economy* 103 (3): 624—60, June.
- [40] Olufowote, John. 2012. Do capital flows respond to movements in the marginal product of capital? What does the data say?. *Journal of International and Global Economic Studies* 5 (2): 77—94.
- [41] Palacios-Huerta, Ignacio. 2001. The human capital of stockholders and the international diversification puzzle. *Journal of International Economics* 54 (2): 309—31.
- [42] Parsley, David C. 2007. Accounting for real exchange rate changes in East Asia. *Journal of International Money and Finance* 26 (8): 1355—77.
- [43] Peersman, Gert & Roland Straub. 2004. Technology shocks and robust sign restrictions in a euro area SVAR. Working Paper Series No. 373, European Central Bank, July.
- [44] Plosser, Charles I. 1989. Understanding real business cycles. *The Journal of Economic Perspectives* 3 (3): 51—78.
- [45] Pigott, Charles. 1993. International interest rate convergence: a survey of the issues and evidence. Federal Reserve Bank of New York Quarterly Review, Winter 1993-1994: 24—37.
- [46] Sa, Filipa & Francesca Viani. 2013. Shifts in portfolio preferences of international investors: an application to sovereign wealth funds. *Review of International Economics* 21 (5): 868—85.
- [47] Schmitt-Grohe, Stephanie. 1998. The international transmission of economic fluctuations: effect of US business cycles on the Canadian economy. *Journal of International Economics* 44 (2): 257—287.

-
- [48] Senbeta, Sisay Regassa. 2011. A small open economy new Keynesian DSGE model for a foreign exchange constrained economy. Working Papers 2011016, University of Antwerp, Faculty of Applied Economics.
- [49] Senhadji, Abdelhak. 1998. Dynamics of the trade balance and the terms-of-trade in LDCs: the S-curve. *Journal of International Economics* 46: 105—131.
- [50] Stockman, Alan C. 1980. A theory of exchange rate determination. *Journal of Political Economy* 88 (4): 673—98, August.
- [51] Tille, Cedric & Eric van Wincoop. 2010. International capital flows. *Journal of International Economics* 80 (2): 157—75, March.
- [52] Wang, Pengfei & Yi Wen. 2007. A defense of RBC: understanding the puzzling effects of technology shocks. Working Paper Series, WP 2007-018B, Federal Reserve Bank of St. Louis.

Chapter 1: Understanding exchange rate jumps — a baseline model

Simon Wan ^{*†}

Abstract

The over-arching objective of this thesis is to understand real exchange rate volatility, with a particular focus on investigating the causes of exchange rate jumps. While the predominant approach in the open macroeconomic literature is to examine the exchange rate volatility that arises from the interaction between nominal shocks and nominal rigidities, this thesis examines the exchange rate volatility that arises from real shocks and real rigidities.

This Chapter serves two purposes in the overall structure of this thesis. First, it explains in greater detail the framework (outlined in section 4.1 of the Introduction) that we use to account for exchange rate movements throughout this thesis. The basic point is that the exchange rate satisfies two equilibrium conditions. After a shock, the goods equilibrium condition pins down the long run level of the exchange rate and the asset equilibrium condition pins down its short run rate of change as it converges onto that level. The overall path of the exchange rate, including its initial jump, reflects the relative size and direction of these two effects. This is simply an accounting framework and is not novel.

The second and main purpose of this Chapter is to set up a baseline model against which the extensions in later Chapters can be compared. This is a model where the uncovered interest parity (UIP) condition holds and there is only one real rigidity, the slow adjustment of capital. Exchange rate volatility arises in this baseline model because real productivity shocks, in the presence of the slow adjustment of capital, cause the real return on home assets to fluctuate, hence leading to financial outflows or inflows that affect the real exchange rate. However, the volatility implied by this baseline model is very small. This is because the per-period adjustment of the exchange rate implied by the UIP condition is small for reasonably sized productivity shocks and especially if there is an endogenous price of capital (Tobin's Q). Later Chapters show how adding features to augment the UIP condition increases exchange rate volatility.

^{*}Nuffield College & Department of Economics, University of Oxford

[†]Email: simon.wan@economics.ox.ac.uk

Address: Nuffield College, New Road, Oxford OX1 1NF, United Kingdom

Contents

1	Introduction	28
1.1	Related literature	30
1.2	Structure of this Chapter	35
2	A framework to account for exchange rate jumps	35
2.1	Goods market	36
2.2	Asset market	40
2.3	Model summary	40
2.4	Jumps reflect differences between short- and long-run changes	42
2.5	Examining exchange rate jumps using model algebra	44
2.6	A graphical representation	49
3	A Baseline Frictionless Model	53
3.1	Households	53
3.2	Consumption	55
3.3	Capital goods producers	56
3.4	Firms	57
3.5	Equilibrium conditions	58
4	Model properties and analysis	59
4.1	The condensed linearised model	59
4.2	Simulation of a technology shock	61
4.3	The effect of forward-looking consumers and Tobin's Q	65
5	Concluding remarks	70
	Appendix	75
1	Deriving the condensed log-linearised model	75

2	Deriving the time path of the exchange rate	76
3	Equilibrium dynamics in the Baseline Model	79
4	Simulation of a temporary shock	84

1 Introduction

The overall aim of this thesis is to better understand real exchange rate determination, with a particular focus on the causes of exchange rate jumps. As discussed in the Introduction, we take a slightly different approach to the one that is predominant in the literature. Instead of focusing on the volatility that arises from the interaction between nominal rigidities and nominal shocks, we consider instead the volatility that arises from the interaction between real rigidities and real shocks. We do this because there is some suggestion in the empirical literature that real shocks and rigidities are important in explaining economic fluctuations and hence it is worthwhile to better understand the transmission of real shocks to exchange rates. In this Chapter we present a very simple model of exchange rate determination. The only rigidity is the slow adjustment of capital. This forms the baseline model of this thesis against which the extensions in later Chapters can be compared.

This Chapter serves two purposes in the overall structure of this thesis. First, we explain in full detail the basic framework (introduced in section 4.1 of the Introduction) that will be applied in order to account for exchange rate movements. This framework is not novel and is simply an accounting method. Recall the underlying premise of this framework from table 1 of the Introduction. That is, the overall path of the exchange rate after a shock is determined by two factors: the long run level of the exchange rate and its short run rate of change as it converges onto that level. We demonstrate that goods equilibrium conditions pin down the *long run level* of the exchange rate while asset equilibrium conditions determine its expected *per-period adjustment in the short run*. The initial jump of the exchange rate (if there is one) simply represents the differences in size and direction between these two effects.

For the purpose of illustration, suppose the long run level is appreciated (relative to

starting point) and the cumulative per-period appreciation in the short run is larger than the long run change. In order for both equilibrium conditions to hold, the exchange rate initially depreciates by a magnitude equal to the difference between the short and long run changes¹. This initial depreciation represents the extent to which the exchange rate must be initially under-valued, relative to its long run level, so that investors are willing, in subsequent periods, to bid up its value by the amount required by the asset equilibrium condition. This framework is merely a mechanical way of accounting for exchange rate movements. Further economic intuition needs to be supplied to explain how the long run and short run effects themselves arise.

The second and main purpose of this Chapter is to use this framework in order to understand how real rigidities can give rise to exchange rate jumps and to understand whether a baseline (and mostly frictionless) model such as the one developed in this Chapter can generate a plausible degree of volatility. There are two results of this exercise. First, we explain how real shocks interact with real rigidities to give rise to exchange rate volatility. The key is that, because capital adjustment is slow and costly, shocks to aggregate productivity cause changes to the real return on domestic assets and hence lead to financial inflows or outflows that affect the real exchange rate.

For instance, suppose that there is a permanent decline in home productivity. The real return on home investments falls because the home capital stock cannot decumulate to its new long run equilibrium level immediately. Investors substitute into holding foreign assets instead of home assets, causing financial outflows that put downward pressure on the exchange rate. This happens until the home currency is sufficiently under-valued with respect to its long run level that investors are willing to hold onto home assets.

The second result of this exercise is that in this type of frictionless model, the exchange

¹This scenario is represented by the heavy dashed line in the bottom right corner of table 1 in the Introduction.

rate volatility implied by the transmission channel described above is very small. This is because in this baseline model, the uncovered interest parity (UIP) condition holds. The UIP condition only requires that the exchange rate adjust so as to equalise common currency home and foreign interest rates. This means that, after the negative productivity shock described above, the exchange rate initially only has to be under-valued (relative to its long run level) to the extent that its subsequent upward adjustment to the long run level equalises the common currency returns on home and foreign assets. The key point is that, in the presence of an endogenous asset price (Tobin's Q), productivity shocks (that lead to reasonably sized fluctuations in other variables) only generate small differences between home and foreign interest rates and hence the burden of adjustment on the exchange rate is accordingly muted.

Other frictions need to be present in order for real shocks and rigidities to generate a significant degree of exchange rate volatility. Later Chapters show that adding imperfect asset substitutability and financial frictions achieves this. In this Chapter, the jumps that we focus on are depreciations although this is for illustrative purposes and the model (like all other models in this thesis) is symmetric (in the sense that a jump in the opposite direction has an analogous explanation).

1.1 Related literature

Exchange rate determination

As was discussed in the main Introduction, this thesis is broadly related to the open macroeconomic literature on exchange rate determination. Bailliu and King (2005) provide a survey of this work. One of the key features in this literature is that nominal prices are modelled as being sticky in the short run. The most common experiment is

to analyse the effect of an exogenous shock to monetary policy on the nominal exchange rate. Because nominal prices are sticky, changes to monetary policy lead to changes in real interest rates and hence affect exchange rates. Dornbusch (1976), Frenkel (1976), Lucas (1982), and Stockman (1980) are early examples of this body of work².

The next major development came with the addition of microfoundations to describe consumption behaviour in Obstfeld and Rogoff (1995). This essentially meant using a standard Euler equation to model aggregate consumption. Other developments (Lane [2001] provides a survey) to the new baseline set by Obstfeld and Rogoff have included features that are now considered standard in DSGE models such as using Calvo pricing to model price stickiness and using a Taylor rule to model monetary policy. Together, these developments have led to the emergence of a class of conventional (small) open economy models typified by Gali and Monacelli (2005). The key common features include: an Euler equation; Dixit-Stiglitz aggregation of home and foreign goods; Calvo pricing and a new Keynesian Phillips curve; the law of one price and the uncovered interest parity condition. The implications for the exchange rate are qualitatively similar to those of Dornbusch.

How does this Chapter relate to this body of work? As we discussed in the main Introduction, this Chapter (and this thesis in general) shares the same broad aim as this body of work, that is, understanding exchange rate determination. However, instead of focusing on the interaction between nominal rigidities and nominal shocks, we focus on the exchange rate volatility arising from real shocks and real rigidities. Hence, we share many features with (for instance) Gali and Monacelli (2005): Euler consumption, CES goods aggregation, the law of one price, and the UIP condition. However, unlike this literature, we abstract from nominal rigidities and focus on real rigidities such as the

²See section 2.1 of the Introduction for a fuller discussion.

adjustment of the capital stock, as was emphasised by the real business cycle (RBC) literature (Kydland and Prescott, 1982; Plosser, 1989). We show that real rigidities interacting with real shocks can generate exchange rate behaviour that is qualitatively similar to that which is generated by nominal rigidities and nominal shocks.

Abstracting from nominal rigidities in open economies is not new. For instance, Meredith (2007) and Sa and Viani (2013) embed a flex-price RBC model in an open economy. In terms of specific model features, we are closest to these papers. The focus of these authors, however, is not exchange rate determination and they do not explain how these rigidities affect exchange rates. For instance, Sa and Viani (2013) explain real exchange rate movements in their simulations in terms of changes to relative national consumption without reference to the effect of the real rigidities they nest in their model. In this thesis, we aim to examine the role of these rigidities in determining exchange rates in both the short and long run. Hence this Chapter can be broadly interpreted as bridging between the open RBC method of these authors and the aims and objectives of the monetary open macroeconomic literature.

Why do we take this different approach? The main reason is that there is some suggestion in the empirical literature that (i) nominal shocks and rigidities are not sufficient to account for real exchange rate volatility entirely and (ii) real shocks and rigidities are important in explaining other economic fluctuations and hence it is worthwhile trying to understand the transmission of real shocks to the exchange rate. Regarding (i), Chari, Kehoe and McGrattan (2002) find that in order for monetary shocks to generate the same real exchange rate volatility as in the data, nominal prices have to be predetermined for at least a year and agents must exhibit an equally implausibly high degree of risk aversion. Similarly, Crucini, Shintani and Tsuruga (2013) find that nominal shocks account for less than a quarter of the forecast error variance of the real exchange rate

at a 3-month horizon and this dissipates to less than 15% at the 12-month horizon.

With respect to (ii), there is some support for focusing on real variables. Baxter (1994), using low-frequency data, finds support for a simple long-run link between the real interest rate differential and the real exchange rate. Chakraborty (2009) and Hayashi and Prescott (2002) find that the exogenous productivity shocks can explain a large proportion of fluctuations in Japan over the 1980s-1990s. Chakraborty and Otsu (2013) make the same finding about emerging markets. Peersman and Straub (2004) find that, in the Euro area, technology shocks account for around a quarter of fluctuations in hours worked from 1982 to 2002. Their conclusion is that “the results are in favour of the RBC paradigm”: a flexible price model in which real shocks are propagated via real rigidities. It is worth noting that Meese and Rogoff (1988) found that focusing on monetary shocks in exchange rate models may be a misspecification because shocks are predominantly real³. Hence, because real shocks are empirically significant, their effect on exchange rates (alongside the effect of monetary nominal shocks) is worth exploring⁴.

Currency crises

Within the broad theme of exchange rate determination, we are interested specifically in the area of exchange rate jumps. Hence it is natural also to look at the currency crisis literature that analyses rapid exchange rate depreciations. This is a body of work that attempts to understand the circumstances that may lead to speculative attacks on fixed exchange rate pegs, hence causing rapid and large devaluations. Burnside, Eichenbaum and Rebelo (2008) provide an overview.

³This forms part of the broader issue that macroeconomic models have performed poorly in explaining or forecasting exchange rate behaviour (the “disconnect puzzle”, Obstfeld and Rogoff, 2001). For instance, Meese and Rogoff (1983) found that no existing structural model could outperform a simple naive random walk at short and medium horizons.

⁴See section 3.2 of the Introduction for a fuller discussion of our rationale.

The first-generation models of currency crises stress the inevitable nature of rapid devaluations if there is an underlying expansionary monetary trend (Krugman, 1979). As soon as forward-looking investors expect that foreign reserves will be depleted they launch speculative attacks on the peg that force a devaluation. Second-generation models (Obstfeld, 1986), introduce the concept that expectations of currency crises may be self-fulfilling. The third-generation models (Aghion, Bacchetta and Banerjee, 2004; Cespedes, Chang and Velasco, 2004 and 2012; Krugman, 1999) are responses to the Asian Crisis of 1997-1998 and stress currency mismatch: firms and banks hold assets largely denominated in the local currency but hold liabilities in foreign currency. These models also emphasise self-fulfilling expectations: an expectation of depreciation worsens the net debt position of home firms, precipitating large capital outflows and downward pressure on exchange rates.

The focus of the currency crisis literature is specific. It attempts to answer a particular question about what circumstances make fixed pegs untenable. The methodology of this literature is also somewhat restricted. Some currency crisis models are partial equilibrium models (e.g. Cespedes, Chang and Velasco, 2012). Furthermore, even general equilibrium currency crisis models are often static one-period models that focus on the initial period of depreciation (e.g. Aghion *et al.* and Cespedes *et al.* 2004). This is because currency crisis models are mostly concerned with the initial period of devaluation and are not concerned with the subsequent dynamic adjustment of the exchange rate after a shock. However, we often observe this type of subsequent adjustment (as in figure 1 in the Introduction) and hence we are interested in investigating it in this thesis.

This thesis and this body of literature share the same area of focus in the sense that we are also interested in sharp changes in exchange rates. However, we extend this focus

from the concept of devaluing fixed pegs to a more general examination of how jumps in exchange rates can occur. This allows us to cover floating rates that in theory should not be vulnerable to the kind of speculative attacks that the currency crisis literature is interested in investigating. This is important because rapid changes in exchange rates are not limited to those currencies that have been forced off pegs. The 2008 financial crisis saw sharp falls of the Australian dollar, the pound sterling, the Canadian dollar, the Swedish krona, and many other floating currencies. This also means that this Chapter builds a bridge between the area of interest of the currency crisis literature (i.e. rapid changes in exchange rates) and the microfounded methodology of the open macroeconomic literature discussed above. This updates the intuitive elements of currency crisis models (e.g. Krugman, 1999) with standard features of a multi-period general equilibrium framework.

1.2 Structure of this Chapter

In this Chapter, we present two models. Section 2 presents a very simple stylised caricature of a model. All we aim to do in this section is explain in more detail the basic framework (outlined in section 4.1 of the Introduction) that we use to present the results throughout this thesis. Sections 3 and 4 then extend this stylised example by adding microfounded behaviour. We demonstrate that this baseline frictionless model generates only a small degree of exchange rate volatility.

2 A framework to account for exchange rate jumps

Recall from section 4.1 of the Introduction that we use a very simple framework to account for exchange rate movements in this thesis. Essentially, the overall path of the

exchange rate after a shock is determined by (i) its long run level and (ii) its rate of change as it converges onto that level. The purpose of this section is to present a very stylised caricature of a model that illustrates this accounting framework. In section 3 we build a full model with microfounded consumption and investment behaviour and numerically show that the results are qualitatively similar (although less analytically tractable).

This is a simple small open economy and so foreign variables are taken as exogenous or have *ad hoc* specifications. We consider supply and demand for consumption goods before turning to asset markets.

2.1 Goods market

Domestic goods production

The production side of this economy follows standard RBC specifications (Kydland and Prescott, 1982; Plosser, 1989). There is a homogeneous home-produced good, Y , whose production function is given by a simple Cobb-Douglas technology, where $\alpha \in (0, 1)$ is a parameter, K is the capital stock, and A is an exogenous variable capturing productivity

$$Y_t = A_t K_t^\alpha \tag{1}$$

Following Luk and Vines (2011), we assume that capital goods are built one period in advance and so firms make their production decision one period in advance as well. At the end of period t , firms decide how many units of capital to purchase from capital goods producers. After production has occurred, firms sell back any undepreciated capital.

The price of capital is fixed at 1. This simplifies the analytical solution by keeping Tobin's Q fixed, hence removing a jump variable. (In section 3, we introduce a varying price of capital Q that endogenises the investment decision.) Firms fund this purchase of capital goods by issuing real bonds in period t that pay a return R_{t+1} after production has occurred in the next period. This gives rise to the home asset. Hence the firm solves

$$\max_{K_t} \{ \mathcal{E}_t (Y_{t+1} + (1 - \delta) K_{t+1} - R_{t+1} K_{t+1}) \} \text{ subject to (1)}$$

This yields a first-order condition

$$\mathcal{E}_t (R_{t+1}) = \mathcal{E}_t \left((1 - \delta) + \alpha \frac{Y_{t+1}}{K_{t+1}} \right)$$

which implies that the realised return on home capital is given by

$$R_t = (1 - \delta) + \alpha \frac{Y_t}{K_t} \tag{2}$$

Capital goods producers build capital goods by combining undepreciated capital with an investment I of consumption goods. At the end of period t , capital goods producers build stock K_{t+1} of capital goods for production in the next period. Hence capital evolves according to

$$K_{t+1} = (1 - \delta) K_t + I_t \tag{3}$$

where δ is the rate of depreciation. Capital is thus predetermined and slow to adjust.

Consumption

The consumption side of this economy is standard (Gali and Monacelli, 2005; Obstfeld and Rogoff, 1995). Within every period, consumption is split between home and foreign goods that are imperfectly substitutable. We assume that aggregate consumption is a constant elasticity of substitution index of home- and foreign-produced goods

$$C_t = \left[\gamma^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (4)$$

where C_H denotes consumption of home goods and C_F denotes consumption of foreign goods. $\gamma \in (0, 1)$ represents the degree of home bias in goods consumption and η is the price elasticity of demand between home and foreign goods. We assume that the aggregate price index faced by the home household takes a similar form

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1-\gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (5)$$

where domestic consumers pay a price P_H for home-produced goods and a price P_F for foreign-produced goods.

In order to reduce the number of jump variables in this stylised example even further, we treat aggregate consumption as fixed at $\bar{C}$. This is a strong assumption but we show that it does not qualitatively affect the results. In section 3 we drop this assumption and introduce microfounded consumption behaviour driven by standard Euler dynamics. The results are qualitatively similar in section 3 but the analysis becomes less tractable - hence we first introduce this stylised example in this section.

It is then straightforward to show that demand for home- and foreign-produced goods

is given by the standard forms

$$C_{Ht} = \gamma \bar{C} \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (6)$$

$$C_{Ft} = (1 - \gamma) \bar{C} \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} \quad (7)$$

Similar to Gertler, Gilchrist and Natalucci (2007), we assume that external demand for home-produced goods is given by

$$C_{Ht}^* = (1 - \gamma) \bar{C} (P_{Ht}^*)^{-\eta} \quad (8)$$

P_H^* is the price paid by foreign consumers for home-produced goods. Following Gali and Monacelli (2005), we assume that the law of one price holds

$$P_{Ft} = E_t \quad (9)$$

$$P_{Ht}^* = \frac{P_{Ht}}{E_t} \quad (10)$$

E is the real exchange rate, defined as the price of foreign goods in terms of home goods⁵. An increase in E is a depreciation for the home country. We treat the home good as the numeraire (Sa and Viani, 2013)

$$P_{Ht} = 1 \quad (11)$$

Equilibrium in the market for home-produced goods equates supply of the home good with total demand

$$Y_t = C_{Ht} + C_{Ht}^* + I_t \quad (12)$$

⁵Sa and Viani (2013) define E as the price of home goods relative to foreign goods.

2.2 Asset market

Investors can either hold assets in the home firm for a return of R or invest in a foreign asset for a riskless return of R^* foreign goods. Arbitrage between home and foreign assets implies

$$\mathcal{E}_t(R_{t+1}) = \mathcal{E}_t\left(R^* \frac{E_{t+1}}{E_t}\right)^\phi \quad (13)$$

Equation (13) states that the common currency expected return on home and foreign assets must be equal after some discount factor on foreign assets ϕ . The parameter ϕ can be interpreted as capturing the extent of bias in asset markets or the degree of capital immobility across national borders. Setting $\phi = 1$ gives us the standard uncovered interest parity condition.

We choose this equation because it very parsimoniously captures the per-period adjustment that is required of exchange rates in equilibrium. The UIP condition captures the key arbitrage equation in a frictionless asset market and thus represents a baseline specification. Recent examples of models in the literature that have employed some form of this assumption include Claus (2011), Gertler, Gilchrist and Natalucci (2007), and Ueda (2012). Chapters 2 and 3 show that augmenting the UIP condition with other features increases exchange rate volatility.

2.3 Model summary

The non-linear system consisting of equations (1)-(3) and (5)-(13) describes the equilibrium dynamics of the variables

$$\{Y_t, K_t, R_t, I_t, C_{Ht}, C_{Ft}, P_t, P_{Ht}, P_{Ft}, E_t, C_{Ht}^*, P_{Ht}^*\}_{t=0}^\infty$$

given an exogenous process for A_t .

We condense the model by log-linearising around the steady state⁶. The system condenses to the following three equations (see Appendix 1 for derivation)⁷

$$\text{Goods equilibrium: } \bar{Y} (\hat{A}_t + \alpha \hat{K}_t) = \bar{C} \eta (1 - \gamma^2) \hat{E}_t + \bar{I} \hat{I}_t \quad (14)$$

$$\text{Asset equilibrium: } \phi \mathcal{E}_t (\hat{E}_{t+1} - \hat{E}_t) = \frac{\alpha \beta \bar{Y}}{\bar{K}} (\mathcal{E}_t (\hat{A}_{t+1}) - (1 - \alpha) \hat{K}_{t+1}) \quad (15)$$

$$\text{Evolution of capital: } \hat{K}_{t+1} = (1 - \delta) \hat{K}_t + \delta \hat{I}_t \quad (16)$$

This condensed system describes the equilibrium dynamics, up to a first-order approximation, of the variables $\{\hat{K}_t, \hat{I}_t, \hat{E}_t\}_{t=0}^{\infty}$, given an exogenous process for $\hat{A}_t$.

For the purpose of illustration, we consider a permanent negative productivity shock such that $\hat{A} = \tilde{A} < 0$ at time zero. Solving the three equations above for $\hat{A} = \tilde{A} < 0$, we find the new steady state. Capital decumulates to a lower level, and the exchange rate converges on an appreciated level (the $\sim$ symbol denotes the new steady state level)

$$\begin{aligned} \tilde{K} &= \frac{\tilde{A}}{1-\alpha} < 0 \\ \tilde{E} &= \frac{\tilde{A}}{\eta(1-\alpha)(1-\gamma^2)} < 0 \end{aligned}$$

Finally, we characterise out-of-steady-state dynamics. We solve for the state space solution for the two endogenous variables $(\hat{I}, \hat{E})$ in terms of the state variables $(\hat{A}, \hat{K})$

⁶As we discussed in section 4.2 of the Introduction, log-linearisation is a common technique in open economy macroeconomics. However, although we consider small or temporary shocks, we are also interested in potentially large deviations from steady state. Using non-linear solution methods is thus an obvious extension. In the Introduction, we offer three brief defences of our choice of solution method. To recapitulate: First, it is simple and allows us to retain non-numerical results. Second, some of the techniques we apply in Chapters 2 and 3 require the use of a linear approximation of the model. Third, it is not clear how important the key element not captured by linearisation (precautionary savings) is.

⁷ $\bar{x}$ denotes the steady state level and $\hat{x}$ denotes the log-deviation from that steady state; $\hat{x} \approx \log(\frac{x}{\bar{x}})$.

using the method of undetermined coefficients (see Appendix 2 for explicit solutions)

$$\begin{bmatrix} \hat{I}_t \\ \hat{E}_t \\ \hat{K}_{t+1} \\ \hat{A}_t \end{bmatrix} = \begin{bmatrix} \mathbf{i}_1 & , & \mathbf{i}_2 \\ \mathbf{e}_1 & , & \mathbf{e}_2 \\ \delta \mathbf{i}_1 & , & 1 - \delta + \delta \mathbf{i}_2 \\ 1 & , & 0 \end{bmatrix} \begin{bmatrix} \tilde{A} \\ \hat{K}_t \end{bmatrix}$$

where $\mathbf{i}_1$, $\mathbf{i}_2$, $\mathbf{e}_1$, and $\mathbf{e}_2$ are constant coefficients to be found. We denote the time period when the new steady state is reached as $\tilde{t}$.

2.4 Jumps reflect differences between short- and long-run changes

We are interested in exchange rate jumps following shocks. This involves understanding the sign and magnitude of $\hat{E}_0$. From inspecting equations (14) and (15), we see that the exchange rate enters into the model in two ways. First, it enters into the goods equilibrium condition as a *level* - the level of the relative price clears the goods market. Second, it enters into the asset equilibrium condition as a *first difference in levels* - the rate of change of that price is a relative return between home and foreign assets that ensures no arbitrage in international asset markets.

It is evident that (i) goods equilibrium determines the new long-run level that the exchange rate converges on after a shock; (ii) asset market equilibrium determines the per-period adjustment of the exchange rate as it moves to this new long-run level. Of course, the level of the exchange rate must clear the goods market at every period and so the goods market equilibrium condition is not only relevant in the long run. However, as we will see, it is the final level of the exchange rate that we are interested in as this determines the size of the initial jump.

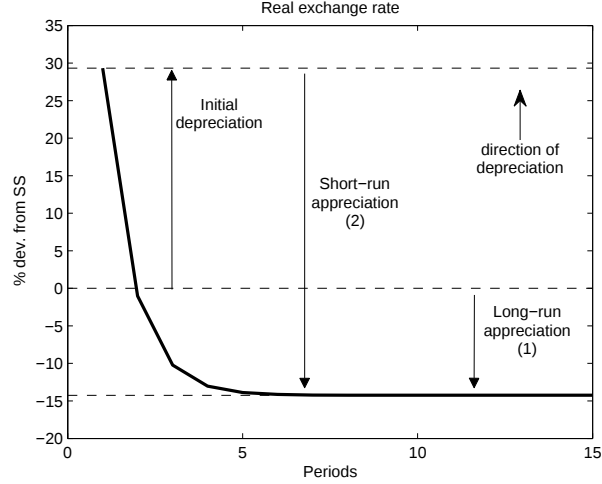
Consider a permanent decrease in home productivity. The supply of home goods permanently declines. In order for the goods market to clear, the price of home goods, relative to foreign goods, must rise and so the level of the exchange rate must appreciate at the new steady state (i.e. $\hat{E} \downarrow$ in the long run).

The short-run adjustment of the exchange rate to its new long-run level depends on the asset equilibrium equation. Because the capital stock is slow to adjust, a negative productivity shock makes the right-hand side of equation (15) negative. Inspection of the left-hand side of (15) tells us the exchange rate is expected to appreciate ($\hat{E} \downarrow$) along the adjustment path until the capital stock decumulates to its new long-run level at which point the right-hand side of (15) returns to zero and the exchange rate will then remain constant. So, the exchange rate appreciates along the adjustment path, with the speed of its adjustment being determined by the speed with which the capital stock decumulates to its new long-run level.

The intuition is simple. The return on home assets falls because the capital stock is slow to decumulate, causing the marginal product of capital to fall. In order for the asset market to be in equilibrium, investors who own home assets must be compensated so that they are satisfied with holding onto these assets. The appreciation of the exchange rate along the adjustment path implied by equation (15) achieves this by equalising the common currency expected returns on home and foreign assets, thus ensuring no arbitrage in international asset markets.

This implies a way to account for the initial jumps of the exchange rate. Whether there is an initial jump of the exchange rate (and its size and direction) depends on the relative magnitudes and directions of its new long-run level and its short-run adjustment. If the goods market equilibrium requires a long-run *level* of, say, -3% but the asset equilibrium requires a cumulative *movement* of -5% along the adjustment path, then

Figure 1: The path of the exchange rate can be accounted for by a combination of two effects. A short-run appreciation (2) that is more negative than the long-run change (1) implies an initial depreciation.



the exchange rate must initially jump up (depreciate) by 2% to allow both equilibrium conditions to hold. The “more-appreciated” (i.e. more negative) the short-run appreciation is compared with the long-run level of the exchange rate, then the larger is the initial depreciation. This stylised scenario is illustrated in figure 1. Of course, these conditions are entirely dependent on the numerical parameterisation of the model. If the magnitudes and directions of the long-run and short-run effects coincide then there is no initial jump. We now examine this claim using the model algebra.

2.5 Examining exchange rate jumps using model algebra

From our state space solution⁸, we can express the initial jump in the exchange rate as

$$\hat{E}_0 = \mathbf{e}_1 \tilde{A} + \mathbf{e}_2 \hat{K}_0 = \mathbf{e}_1 \tilde{A}$$

⁸Recall our notation: $\tilde{A}$, $\tilde{E}$, and $\tilde{K}$ are the new long-run levels reached at period $\tilde{t}$. Out-of-steady-state adjustment follows:
$$\begin{bmatrix} \hat{I}_t \\ \hat{E}_t \end{bmatrix} = \begin{bmatrix} \mathbf{i}_1 & \mathbf{i}_2 \\ \mathbf{e}_1 & \mathbf{e}_2 \end{bmatrix} \begin{bmatrix} \tilde{A} \\ \hat{K}_t \end{bmatrix}.$$

where the second equality holds because $\widehat{K}_0 = 0$ since $\widehat{K}$ is predetermined.

For a sensible parameterisation (see table 1) $\widehat{E}_0 \approx -0.5\tilde{A} > 0$, and so the exchange rate does initially depreciate ($\widehat{E} \uparrow$) before gradually appreciating to its long-run level. We show that this initial jump, $\widehat{E}_0 = \mathbf{e}_1 \tilde{A}$, is the result of the long-run and short-run effects discussed previously. Rearrange equation (15) into the form $\mathcal{E}_t(\widehat{E}_{t+1} - \widehat{E}_t) = \mathbf{\Gamma}(t+1)$, for some placeholder function $\mathbf{\Gamma}(t+1) \equiv \frac{\alpha\beta\bar{Y}(\tilde{A} - (1-\alpha)\widehat{K}_{t+1})}{\phi\bar{K}}$. This tells us that $\widehat{E}_0 = \mathcal{E}_0(\widehat{E}_1 - \mathbf{\Gamma}(1))$. We cannot use this expression alone to solve for $\widehat{E}_0$ because this expression also depends on the expected future level $\mathcal{E}_0(\widehat{E}_1)$. However, at time $\tilde{t}$ the exchange rate will reach the new steady state level $\tilde{E}$, which is known. So we iterate equation (15) forward to the period $\tilde{t} - 1$. That is

$$\begin{aligned}\widehat{E}_0 &= \widehat{E}_1 - \mathbf{\Gamma}(1) \\ \widehat{E}_1 &= \widehat{E}_2 - \mathbf{\Gamma}(2) \\ &\dots \\ \widehat{E}_{\tilde{t}-1} &= \widehat{E}_{\tilde{t}} - \mathbf{\Gamma}(\tilde{t}) = \tilde{E} - \mathbf{\Gamma}(\tilde{t})\end{aligned}$$

And we combine all $\tilde{t}$ expressions above into a new expression for $\widehat{E}_0$

$$\begin{aligned}\widehat{E}_0 &= \widehat{E}_1 - \mathbf{\Gamma}(1) \\ &= \widehat{E}_2 - \mathbf{\Gamma}(1) - \mathbf{\Gamma}(2) \\ &\dots \\ &= \tilde{E} - \mathbf{\Gamma}(1) - \mathbf{\Gamma}(2) - \mathbf{\Gamma}(3) - \dots - \mathbf{\Gamma}(\tilde{t}-1) - \mathbf{\Gamma}(\tilde{t}) \\ &= \tilde{E} - \mathcal{E}_0\left(\sum_{s=1}^{\tilde{t}} \mathbf{\Gamma}(s)\right) \\ &= \tilde{E} - \mathcal{E}_0\left(\sum_{j=1}^{\tilde{t}} \Delta\widehat{E}_j\right)\end{aligned}$$

at which point it becomes clear that the initial jump in the exchange rate $\hat{E}_0$ is equal to the exchange rate's *future long-run level* minus the *integral of expected future per-period changes*. By solving for the time-path of the exchange rate and capital (see Appendix 2), we find an explicit form to this expression

$$\underbrace{\hat{E}_0}_{\text{initial jump}} = \underbrace{\tilde{E}}_{\text{(long-run level < 0)}} - \underbrace{\frac{\tilde{A}\alpha\beta\bar{Y}}{\delta\phi\bar{K}} \left(\frac{1}{\mathbf{i}_1(1-\alpha)} - \delta \right)}_{\text{(cumulative sum of future exchange rate changes < 0)}} \quad (17)$$

So, the initial jump of the exchange rate can be decomposed into the long-run level and short-run adjustment effects⁹. The first term on the right-hand side of equation (17), $\tilde{E}$, is the level of the exchange rate that clears the goods market in the long run. Of course, the exchange rate clears the goods market at every period. At every period along the adjustment path, the level of the exchange rate ensures that domestic and external demand for home goods balances its supply. But it is the final level of the exchange rate that we are interested in because it is the final level that determines the exchange rate's initial jump. Note that the goods market equilibrium condition alone cannot pin down the path of the exchange rate because it depends on other endogenous variables (in this case, investment).

The second term on the right-hand side of equation (17), $\frac{\tilde{A}\alpha\beta\bar{Y}}{\delta\phi\bar{K}} \left(\frac{1}{\mathbf{i}_1(1-\alpha)} - \delta \right)$, equals the cumulative sum of expected per-period exchange rate changes ($\mathcal{E}_0 \left(\sum_{j=1} \Delta \hat{E}_j \right)$), which is the total period-by-period appreciation along the adjustment path that is required to equilibrate the asset market (see Appendix 2 for derivation). This is the size of the cumulative strengthening in the exchange rate that is required to keep investors

⁹An empirical model that performs well in forecasting exchange rates explicitly models the interaction between long-run levels and short-run adjustments. The Bank of Canada's exchange rate model (Amano and van Norden, 1993) is notable for its forecasting accuracy. It crucially incorporates long-run effects (prices for Canadian commodities generate a long-run equilibrium level) and short-run effects (interest rate spreads are used to capture short-run dynamics) in an error correction model.

indifferent between home and foreign assets at every period on the adjustment path, given that the home asset return, R , has fallen relative to the foreign asset return.

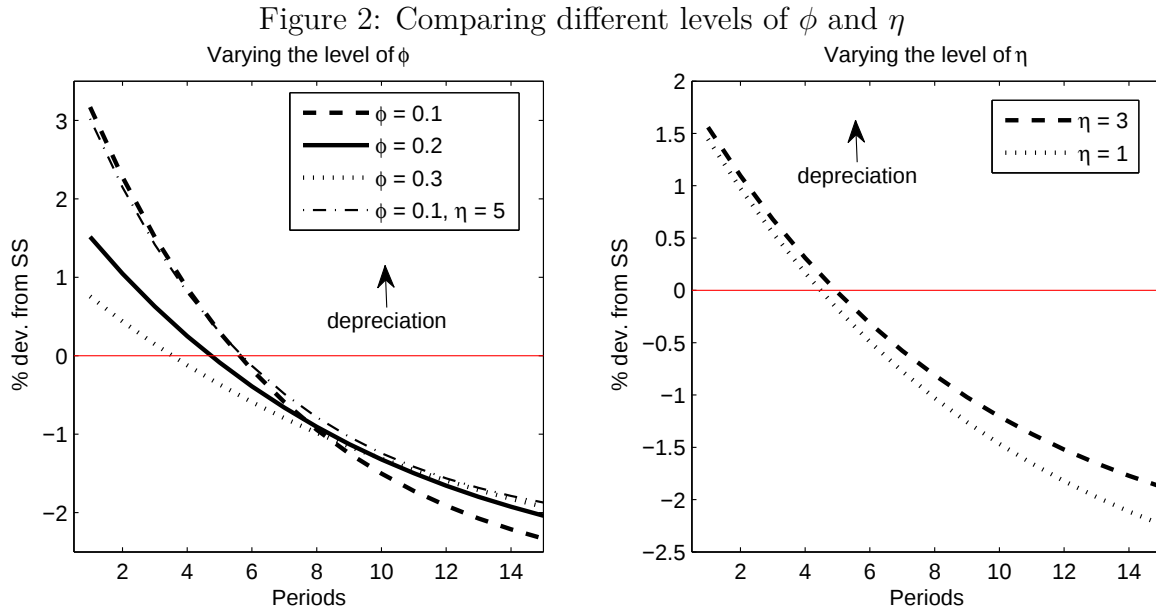
The size and direction of the initial jump in the exchange rate, then, depends on the relative sizes of these two terms. For instance, we get an initial depreciating jump ($\hat{E}_0 > 0$) if the second term in equation (17) - the cumulative size of the short-run per-period adjustment $\mathcal{E}_0 \left(\sum_{j=1} \Delta \hat{E}_j \right)$ - is much “more-appreciated” (more negative) than the first term in equation (17) - the long-run level $\tilde{E}$. The intuition is simple: if we want the exchange rate to appreciate (on a period-to-period basis), then it must be initially under-valued relative to its long-run level, so that market participants are then willing to bid up its value again.

To illustrate: as ϕ decreases, the expected cumulative appreciation $\frac{\tilde{A}\alpha\beta\bar{Y}}{\delta\phi\bar{K}} \left(\frac{1}{i_1(1-\alpha)} - \delta \right)$ becomes more-negative but the long-run level $\tilde{E}$ is unchanged and so the initial depreciation becomes larger. Similarly, as the value of η rises, the long-run level $\tilde{E} = \frac{\tilde{A}}{\eta(1-\alpha)(1-\gamma^2)}$ becomes less-negative (“less-appreciated”)¹⁰. So, again, the exchange rate initially depreciates by more so that there is the same amount of “room” for the short-run appreciation, whose size is unchanged. Numerical simulations in figure 2 confirm this¹¹. Thus, for instance, some combination of a low value for ϕ and a high value for η would produce a large and rapid depreciation after a negative productivity shock.

How is this exchange rate movement brought about from a *structural* point of view? Because of the fall in the home real interest rate, investors wish to hold foreign assets instead of home assets. This causes financial outflows and puts downward pressure on the exchange rate until it is sufficiently under-valued with respect to its long-run equilibrium level. This is the point where the subsequent per-period appreciation raises

¹⁰Since, if home and foreign goods are more substitutable, a smaller change in the level of the exchange rate is needed to clear the goods market for any shock.

¹¹In figure 2, we simulate the stylised example developed in section 2 using the calibration in table 1. We simulate a permanent 3% decline in productivity $\hat{A} = 0.03$.



the common currency return on home assets enough for investors to be satisfied with holding onto home assets. The financial outflows stop, inflows resume, and the exchange rate thus appreciates gradually to its long-run level. The lower ϕ is, the more the common currency home return has to rise before investors are happy to hold home assets and so the more the exchange rate has to be initially under-valued. The higher η is, the less-appreciated is the long-run equilibrium value of the exchange rate, and so (for the same degree of relative under-valuation) the more the exchange rate has to initially depreciate by.

Notice that the exchange rate remains efficient in the informational sense even though investors know, in this perfect foresight model, that it will appreciate in future periods. This future appreciation is only large enough to make investors indifferent between home and foreign assets at every period along the adjustment path. This is why investors cannot use this information to their advantage: there would be no benefit to them if they bid the exchange rate up to its long-run level immediately since the exchange rate would no longer be appreciating which means that home assets would offer an

unambiguously lower return than foreign assets.

Finally, in order for there not to be an initial jump, the size and direction of the long-run change and the short-run change have to coincide. From equation (17), setting $\hat{E}_0 = 0$ would require that $\tilde{E} = \frac{\tilde{A}\alpha\beta\bar{Y}}{\delta\phi\bar{K}} \left(\frac{1}{i_1(1-\alpha)} - \delta \right)$, which implies that $1 = \frac{1}{\delta(1-\alpha)i_1} - \frac{\phi\bar{K}}{\eta(1-\alpha)(1-\gamma^2)\alpha\beta\bar{Y}}$. In order for there not to be a jump, there would need to be a specific set of parameter values that satisfied this condition. Jumps in the exchange rate are thus not the result of a special set of assumptions. The general non-coincidence of the long-run and the short-run effects should not be surprising. One effect follows from the role of the exchange rate as a level, the other from its role as a rate of change, and the two roles differ by an order of integration.

Of course, the initial jump need not be positive (a depreciation). For instance, if the short-run appreciation is insufficiently large, the exchange rate will experience an initial appreciation followed by the further gradual appreciation. This framework is mechanical and parameter-dependent. This is an accounting identity: it is a method for decomposing total changes into separate effects. Economic intuition needs to be supplied to explain why the short-run effect might be larger than the long-run effect or *vice versa*.

2.6 A graphical representation

The results of this stylised model can be summarised diagrammatically. Using the state-space solution and the derivations in Appendix 2, we can express the three equilibrium

conditions of the model as follows

$$\text{Equilibrium between } \hat{E} \text{ and } \hat{K}: \hat{E} = -\frac{\bar{I}\mathbf{i}_1 - \bar{Y}}{\bar{C}_\eta(1-\gamma^2)}\hat{A} + \frac{\bar{Y}\alpha - \bar{I}\mathbf{i}_2}{\bar{C}_\eta(1-\gamma^2)}\hat{K} \quad (18)$$

$$\text{Rate of change of } \hat{E}: \Delta\hat{E} = \frac{\alpha\bar{\beta}\bar{Y}(1-\delta+\delta\mathbf{i}_2)\bar{C}}{\phi\bar{K}(\bar{Y}\alpha - \bar{I}\mathbf{i}_2)}(\hat{A} - \hat{E}\eta(1-\alpha)(1-\gamma^2)) \quad (19)$$

$$\text{Rate of change of } \hat{K}: \Delta\hat{K} = \delta\mathbf{i}_1(\hat{A} - (1-\alpha)\hat{K}) \quad (20)$$

We illustrate this system in the top panel of figure 3. The economy is always on the schedule (equation (18)) which defines the equilibrium relation between $\hat{K}$ and $\hat{E}$ within any period. This schedule has a positive gradient: a higher capital stock implies a higher supply of home goods and so $\hat{E}$ depreciates (i.e. $\uparrow$) in order to clear the goods market. The other equations ((19) and (20)) determine the speed and direction of adjustment of capital and the exchange rate along the equilibrium schedule. From (19) and (20), it can be shown numerically that

$$\begin{aligned} \Delta\hat{K} &> 0 \text{ when } \hat{K} < 0, \Delta\hat{K} < 0 \text{ when } \hat{K} > 0 \\ \Delta\hat{E} &> 0 \text{ when } \hat{E} < 0, \Delta\hat{E} < 0 \text{ when } \hat{E} > 0 \end{aligned}$$

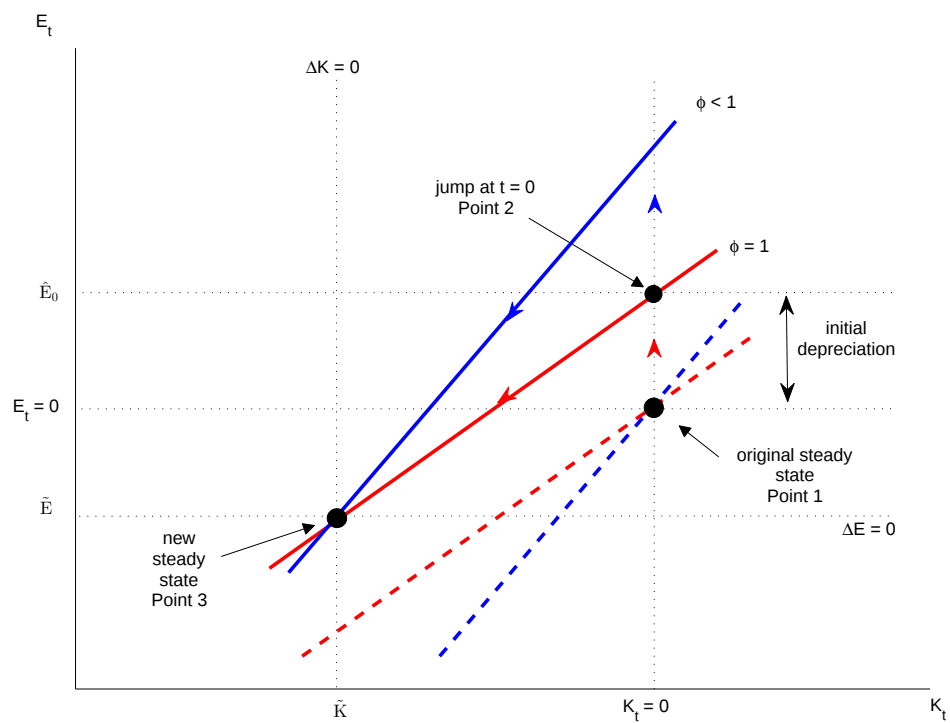
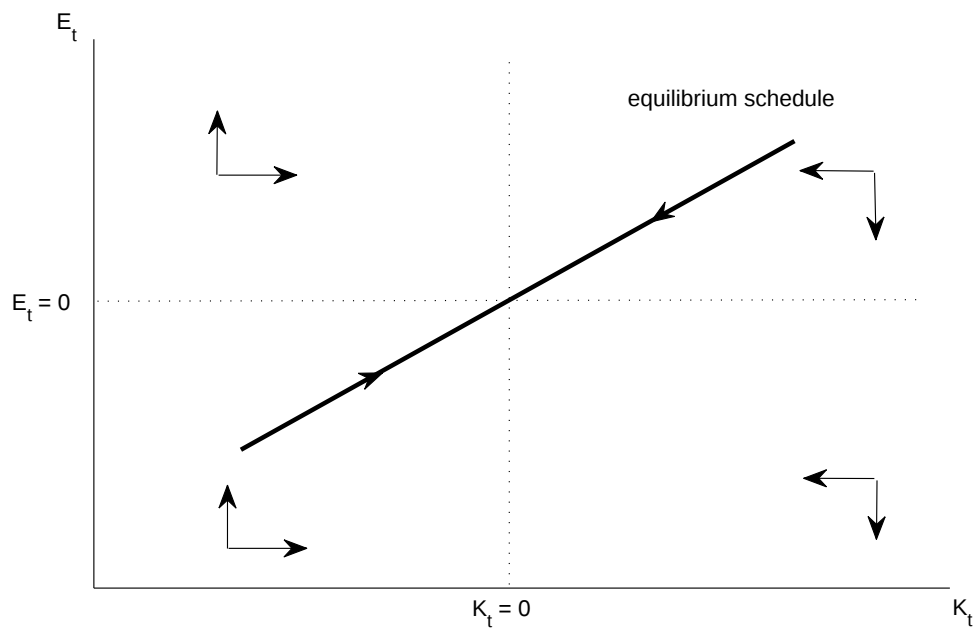
Hence the equilibrium schedule is saddle-path stable¹².

The bottom-panel of figure 3 illustrates the case of a permanent negative productivity shock¹³. To find the new steady state, we set $\hat{A} = \tilde{A} < 0$ and $\Delta\hat{K} = \Delta\hat{E} = 0$. This gives, as before, $\tilde{K} = \frac{\tilde{A}}{1-\alpha} < 0$ and $\tilde{E} = \frac{\tilde{A}}{\eta(1-\alpha)(1-\gamma^2)} < 0$. Point 1 represents the original steady state. When the shock occurs the equilibrium line shifts up by $\frac{\bar{I}\mathbf{i}_1 - \bar{Y}}{\bar{C}_\eta(1-\gamma^2)}\tilde{A}$ units.

¹²We have collapsed the entire model into a system with one predetermined variable ($\hat{K}$), one jump variable ($\hat{E}$), and exactly one unstable root. This system is Blanchard-Kahn stable, indicated by the unique equilibrium pinned down by the saddle-path schedule.

¹³A time series simulation of this shock is presented in figure 6.

Figure 3: Phase diagram



Because capital is predetermined and slow to adjust, the economy shifts vertically to point 2. The exchange rate immediately depreciates at time zero - as we have seen previously algebraically¹⁴. At point 2, $\widehat{K} > \widetilde{K}$ and $\widehat{E} > \widetilde{E}$, and so $\Delta\widehat{K} < 0$ and $\Delta\widehat{E} < 0$: the economy moves down and left (capital decumulates, the exchange rate appreciates) until it reaches the new steady state at point 3.

As ϕ decreases, the equilibrium schedule becomes steeper (the blue lines), and so in order for the schedule to pass through the same long-run level (the point $(\widetilde{E}, \widetilde{K})$) after the shock (which it must, because these long-run levels are pinned down by the shock $\widehat{A}$, which is independent of ϕ), the schedule needs to shift up by more, indicating a larger cumulative appreciation along the adjustment path, which implies a larger initial depreciation - as we saw previously. Conversely, for a sufficiently high value of ϕ , the equilibrium schedule is so flat that in order to pass through the new steady state, the schedule shifts *down* - this would indicate an *initial appreciation* rather than an initial depreciation, reinforcing the fact that the initial jump of the exchange rate is parameter-dependent.

The vertical distance between $\widehat{E}_0$ and $\widetilde{E}$ reflects the cumulative size of the appreciation necessary to keep the asset market in equilibrium. The framework here is analogous to that in Dornbusch (1976): the initial jump represents the extent to which the exchange rate has to under-value (relative to its long run level) in order to compensate for a fall in the domestic real interest rate. The key difference is that here a technology shock combined with the slow adjustment of capital causes the fall in the home real interest rate, while in Dornbusch this is caused by a rise in the domestic money supply combined with the slow adjustment of prices (thus causing real money balances to rise).

¹⁴The initial jump of the exchange rate $\widehat{E}_0$ can be found by rearranging equation (18) and using the fact that $\widehat{K}_0 = 0$ to get $\widehat{E}_0 = -\widetilde{A} \frac{\widetilde{i}_1 - \overline{Y}}{\overline{C}\eta(1-\gamma^2)}$, which is numerically equivalent to the value for $\widehat{E}_0$ found previously ($\widehat{E}_0 = \mathbf{e}_1 \widetilde{A} = \widetilde{E} - \frac{\widetilde{A}\alpha\beta\overline{Y}}{\delta\phi\widetilde{K}} \left(\frac{1}{i_1(1-\alpha)} - \delta \right)$).

3 A Baseline Frictionless Model

In this section, we develop a model with two extensions to the model outlined above. First, we add forward-looking consumers and so consumption is determined by standard Euler dynamics. Second, investment is endogenously determined as an optimal response to Tobin's Q . The results are less analytically tractable but are qualitatively identical to the stylised framework above. This model serves as the baseline specification in this thesis. It is frictionless except for the basic real rigidity of the slow adjustment of capital. The purpose of this section is to show that the real rigidities and shocks in this baseline model generate only a small degree of exchange rate volatility.

3.1 Households

A problem sometimes arises when we add forward-looking consumers to a small open economy. It is known (Schmitt-Grohe and Uribe, 2003) that this system sometimes has no unique steady state because it depends on initial conditions. This means that equilibrium dynamics possess a random walk component¹⁵. A simple way to induce stationarity is to use an endogenous discount factor that depends on the current level of consumption. This pins down a unique steady state level of consumption.

We follow Schmitt-Grohe and Uribe (2003) in our specification of the endogenous discount factor. The representative household has preferences described by the following utility function

$$U_t = \mathcal{E}_t \sum_{i=t}^{\infty} (\theta_i \log(C_i)) \quad (21)$$

¹⁵This is because the interest rate must equal the exogenously-set world interest rate in steady state. And so steady state consumption, which is normally pinned down by the interest rate, is not uniquely determined.

where $\theta_0 = 1$ and $\theta_{t+1} = \theta_t \beta(C_t)$ for $t \geq 0$. The variable β has the functional form (for $\pi > 0$)

$$\beta_t = (1 + \log(C_t))^{-\pi} \quad (22)$$

$\frac{d\beta}{dC} < 0$ and so as current consumption rises, the household becomes more impatient.

The budget constraint is given by

$$C_t + B_{Ht} + B_{Ft} = B_{Ht-1}R_t + B_{Ft-1} \left(R_t^* \frac{E_t}{E_{t-1}} \right)^\phi + \Pi_t \quad (23)$$

On the expenditure side (left-hand side) is aggregate consumption C and also B_H and B_F , which are, respectively, the holdings of home and foreign assets denominated in the home good. On the income side (right-hand side), the household receives returns on its portfolio from the previous period and any profits from the representative firm Π . Holdings of home assets from $t-1$ to t yield a return R_t , which is determined endogenously in general equilibrium. Foreign assets yield a return R^* , which is exogenously determined. The foreign asset return is scaled up by the rate of depreciation of the exchange rate¹⁶. E is the real exchange rate defined as the price of foreign goods in terms of home goods - an increase in E indicates a real depreciation.

The household maximises expected utility (21) subject to the budget constraint (23) and the definition of the discount factor (22). This implies a Lagrangian of the form

$$\begin{aligned} \mathcal{L}_t = & \mathcal{E}_t \sum_{i=t}^{\infty} \theta_i \left\{ \log(C_i) - \lambda_i \left(C_i + B_{Hi} + \frac{B_{Fi}}{E_i} - R_i B_{Hi-1} - R_i^* B_{Fi-1} \frac{E_i}{E_{i-1}} \right) \right\} \\ & - \sigma_i (\beta(C_i) \theta_i - \theta_{i+1}) \end{aligned}$$

¹⁶The foreign asset return is subject to the discount factor ϕ that captures some imperfection in international asset markets (e.g. transaction costs; setting $\phi = 1$ gives us UIP). See section 2.2.

where λ and σ are the Lagrange multipliers. This yields three first-order conditions¹⁷

$$\begin{aligned} /B_H : \theta_t \lambda_t &= \mathcal{E}_t(\theta_{t+1} \lambda_{t+1} R_{t+1}) \\ \lambda_t &= \mathcal{E}_t(\lambda_{t+1} R_{t+1}) (1 + \log(C_t))^{-\pi} \end{aligned} \quad (24)$$

$$/C : 1 = C_t \lambda_t - \frac{\pi \sigma_t}{(1 + \log(C_t))^{1+\pi}} \quad (25)$$

$$/\theta : \sigma_t = \mathcal{E}_t(\sigma_{t+1} (1 + \log(C_{t+1}))^{-\pi}) - \mathcal{E}_t(\log(C_{t+1})) \quad (26)$$

These three equations describe the time path of aggregate consumption. It is clear from equation (24) that, in steady state, consumption is uniquely determined as a function of $\bar{R}$ and the parameter π

$$1 = \bar{R} (1 + \log(\bar{C}))^{-\pi}$$

This solves the problem of non-stationarity. The remaining equations describing consumption behaviour are analogous to those in section 2 and are standard (Gali and Monacelli, 2005).

3.2 Consumption

Within any period, aggregate consumption is divided between home and foreign goods. We assume that aggregate consumption is given by a standard constant elasticity of substitution index of the form

$$C_t = \left[\gamma^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1 - \gamma)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (27)$$

¹⁷A fourth first-order condition with respect to B_F , when combined with (24), simply gives us the asset equilibrium condition, which we list below in equation (39).

where η represents the price elasticity of substitution and γ represents the degree of home bias in consumption. The consumer faces a price of P_H for home goods and P_F for foreign goods. The aggregate price index also has a CES form

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1-\gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (28)$$

It is straightforward to show, given these functional forms, that the domestic demand for home and foreign goods are, respectively

$$C_{Ht} = \gamma C_t \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (29)$$

$$C_{Ft} = (1-\gamma) C_t \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} \quad (30)$$

We take the home good as the numeraire (Sa and Viani, 2013). The law of one price holds and so the price paid by home consumers for foreign goods equals the real exchange rate

$$P_{Ht} = 1 \quad (31)$$

$$P_{Ft} = E_t \quad (32)$$

3.3 Capital goods producers

The production side follows a standard RBC specification (Luk and Vines, 2011). Capital evolves according to (where ξ represents adjustment costs and I is investment by capital goods producers)

$$K_{t+1} = (1-\delta)K_t + I_t - \frac{\xi (K_{t+1} - K_t)^2}{2K_t} \quad (33)$$

At the end of period t , capital goods producers buy back any undepreciated capital from this period at the prevailing price of capital Q_t . At the same time, capital goods producers build and sell quantity K_{t+1} of capital goods to firms at the same price. Hence capital goods producers choose the level of investment I to solve

$$\max_{I_t} \{Q_t K_{t+1} - Q_t (1 - \delta) K_t - P_{Ht} I_t\} \quad \text{subject to (33)}$$

which yields a first-order condition

$$Q_t = P_{Ht} \left(1 - \xi + \xi \frac{K_{t+1}}{K_t} \right) \quad (34)$$

3.4 Firms

The production technology is given by

$$Y_t = A_t K_t^\alpha \quad (35)$$

Because capital goods are built one period in advance, firms must make their production decision one period in advance as well. So, at the end of period t , firms purchase a stock of capital goods K_{t+1} at the current price Q_t . Production takes place in $t+1$ and any undepreciated capital is sold back to capital goods producers at next period's price Q_{t+1} . Firms fund this purchase of capital goods by issuing real bonds to households that pay a return R_{t+1} after production has taken place. This implies that the firms' optimisation problem in period t is given by

$$\max_{K_{t+1}} \mathcal{E}_t (Y_{t+1} - R_{t+1} Q_t K_{t+1} + Q_{t+1} (1 - \delta) K_{t+1}) \quad \text{subject to (35)}$$

This gives a first-order condition

$$\mathcal{E}_t(R_{t+1}Q_t) = \mathcal{E}_t\left((1-\delta)Q_{t+1} + \alpha\frac{Y_{t+1}}{K_{t+1}}\right)$$

which implies that the realised return on home assets is given by

$$R_tQ_{t-1} = (1-\delta)Q_t + \alpha\frac{Y_t}{K_t} \quad (36)$$

So the return on home assets R is determined by the productivity of the home capital stock. R also rises if there is an increase in Q since this represents a capital gain on holding home assets.

3.5 Equilibrium conditions

Equilibrium in the market for home-produced goods is given by equating supply of and demand for home goods

$$Y_t = C_{Ht} + C_{Ht}^* + I_t \quad (37)$$

where external demand for home goods is given by an increasing function of E (Gertler, Gilchrist and Natalucci, 2007)

$$C_{Ht}^* = \bar{C}_{Ht}^* \left(\frac{1}{E_t}\right)^{-\mu} \quad (38)$$

Equilibrium in the asset market is given by the same equation as in section 2 (setting $\phi = 1$ gives us UIP)

$$\mathcal{E}_t(R_{t+1}) = \mathcal{E}_t\left(R_{t+1}^* \frac{E_{t+1}}{E_t}\right)^\phi \quad (39)$$

4 Model properties and analysis

4.1 The condensed linearised model

The non-linear system containing the equations (24)-(26) and (28)-(39) describes the equilibrium dynamics of the variables

$$\{\lambda_t, \sigma_t, C_t, C_{Ht}, C_{Ft}, P_t, P_{Ht}, P_{Ft}, E_t, R_t, Q_t, I_t, Y_t, K_t, C_{Ht}^*\}_{t=0}^\infty$$

given some exogenous process for A_t .

Using the procedure described in Appendix 1, we can condense the model by log-linearising and eliminating variables. This gives us the following system¹⁸

$$\bar{Y}(\hat{A}_t + \alpha\hat{K}_t) = \bar{C}_H\hat{C}_t + (\bar{C}_H\eta(1-\gamma) + \bar{C}_{H\mu}^*)\hat{E}_t + \bar{I}\hat{I}_t \quad (40)$$

$$\hat{K}_{t+1} = (1-\delta)\hat{K}_t + \delta\hat{I}_t \quad (41)$$

$$\phi\mathcal{E}_t(\hat{E}_{t+1} - \hat{E}_t) = -\hat{Q}_t + \mathcal{E}_t \left[\begin{array}{c} \frac{1-\delta}{\bar{R}}\hat{Q}_{t+1} \\ + \left(1 - \frac{1-\delta}{\bar{R}}\right)(\hat{A}_{t+1} - (1-\alpha)\hat{K}_{t+1}) \end{array} \right] \quad (42)$$

$$\hat{Q}_t = \xi(\hat{K}_{t+1} - \hat{K}_t) \quad (43)$$

$$\hat{\sigma}_t\bar{\sigma} = \mathcal{E}_t\left(\frac{\bar{\sigma}}{\bar{R}}\hat{\sigma}_{t+1} - \bar{\lambda}\bar{C}\hat{C}_{t+1}\right) \quad (44)$$

$$\hat{\lambda}_t + \hat{C}_t = \hat{\sigma}_t\left(1 - \frac{1}{\bar{\lambda}\bar{C}}\right) - \frac{(1+\pi)\left(1 - \frac{1}{\bar{\lambda}\bar{C}}\right)}{1 + \log(\bar{C})}\hat{C}_t \quad (45)$$

$$\hat{\lambda}_t + \frac{\pi\hat{C}_t}{1 + \log(\bar{C})} = -\hat{Q}_t + \mathcal{E}_t \left[\begin{array}{c} \hat{\lambda}_{t+1} + \frac{1-\delta}{\bar{R}}\hat{Q}_{t+1} \\ + \left(1 - \frac{1-\delta}{\bar{R}}\right)(\hat{A}_{t+1} - (1-\alpha)\hat{K}_{t+1}) \end{array} \right] \quad (46)$$

As in section 2, we consider the effect of a permanent fall in productivity to $\hat{A} = \tilde{A} < 0$.

It is straightforward to show that capital decumulates to a lower level $\tilde{K} = \frac{\tilde{A}}{1-\alpha} < 0$

¹⁸ $\bar{x}$ denotes the steady state level and $\hat{x}$ denotes the log-deviation from that steady state; $\hat{x} \approx \log(\frac{x}{\bar{x}})$.

Table 1: Parameter calibration

Parameter/Variable	Value	Source
Capital share of income α	0.35	standard e.g. Cooley, Hansen & Prescott (1995)
Depreciation of capital δ	0.025	“
Capital adjustment costs ξ	1	see sensitivity analysis in figure 7
Home bias in goods consumption γ	0.8	see our discussion in Chapter 2 section 4.1
Elasticity of substitution η	2	“
Foreign elasticity of substitution μ	2	“
Elasticity of discount factor π	0.0183	steady-state discount factor = 0.99
Technology shock $\tilde{A}$	-0.03	experiment

and the exchange rate appreciates $\tilde{E} = \frac{\tilde{A}(\bar{Y} - \bar{I})}{(1-\alpha)(C_H\eta(1-\gamma) + \bar{C}_H^*\mu)} < 0$. Since the supply of the home good falls, the exchange rate appreciates $\hat{E} \downarrow$ in the long run to clear goods markets.

Clearly, the accounting method we described in the previous section still holds in a model such as this one with slightly more complex features. We can infer from inspection that the asset equilibrium condition (42) determines the per-period rate of change of the exchange rate, while the goods equilibrium condition (40) pins down the level of the exchange rate at every period. Together, the long run level implied by (40) and the short run cumulative change implied by (42) can account for the overall path of the exchange rate.

In Appendix 3 we show that this model can be collapsed into a system of three equations analogous to the system in section 2.6, hence making the two models qualitatively similar. In short, the application of the accounting method from the previous section is robust to adding the extensions we consider in this baseline model.

4.2 Simulation of a technology shock

Because the full baseline model is less analytically tractable, we conduct numerical simulations of the permanent productivity shock. We parameterise the model using the values in table 1¹⁹ and we consider three values for the parameter $\phi = \{0.1, 1, 2.0\}$, the discount factor in the asset equilibrium condition (42). For an extensive discussion of parameterisation, see section 4.1 in Chapter 2. We consider a permanent 3% decline in productivity. This is presented in figure 4. The responses are qualitatively similar for all values of ϕ .

In response to the shock, output (Y) immediately falls by the same magnitude as the fall in productivity. Output then continues to decline as capital decumulates. Since the productivity of capital goods declines, the demand for capital decreases, which causes the price of capital (Q) to fall initially. Q then recovers as the decumulation of capital raises the marginal product of each remaining unit of capital. Investment (I) optimally follows Q and so initially falls before recovering. The capital stock (K) declines gradually as investment falls. The fall in Q and in the marginal product of capital in the initial period lead to an unanticipated loss on home assets. The return on the home asset (R) thus initially falls. R then recovers as the upward path of Q generates a capital gain on holding home assets.

The real exchange rate

We can then account for the exchange rate behaviour in the middle right panel of figure 4 using the basic schematic diagram introduced in the Introduction and reproduced

¹⁹In order to be conservative in our initial specification of capital adjustment costs, we initially choose a relatively small value for ξ (e.g. Luk and Vines [2011] choose $\xi = 10$). We conduct a sensitivity analysis below to check the effect of setting different values of $\xi \in \{0.1, 1, 10, 100\}$.

Figure 4: Simulation of a technology shock

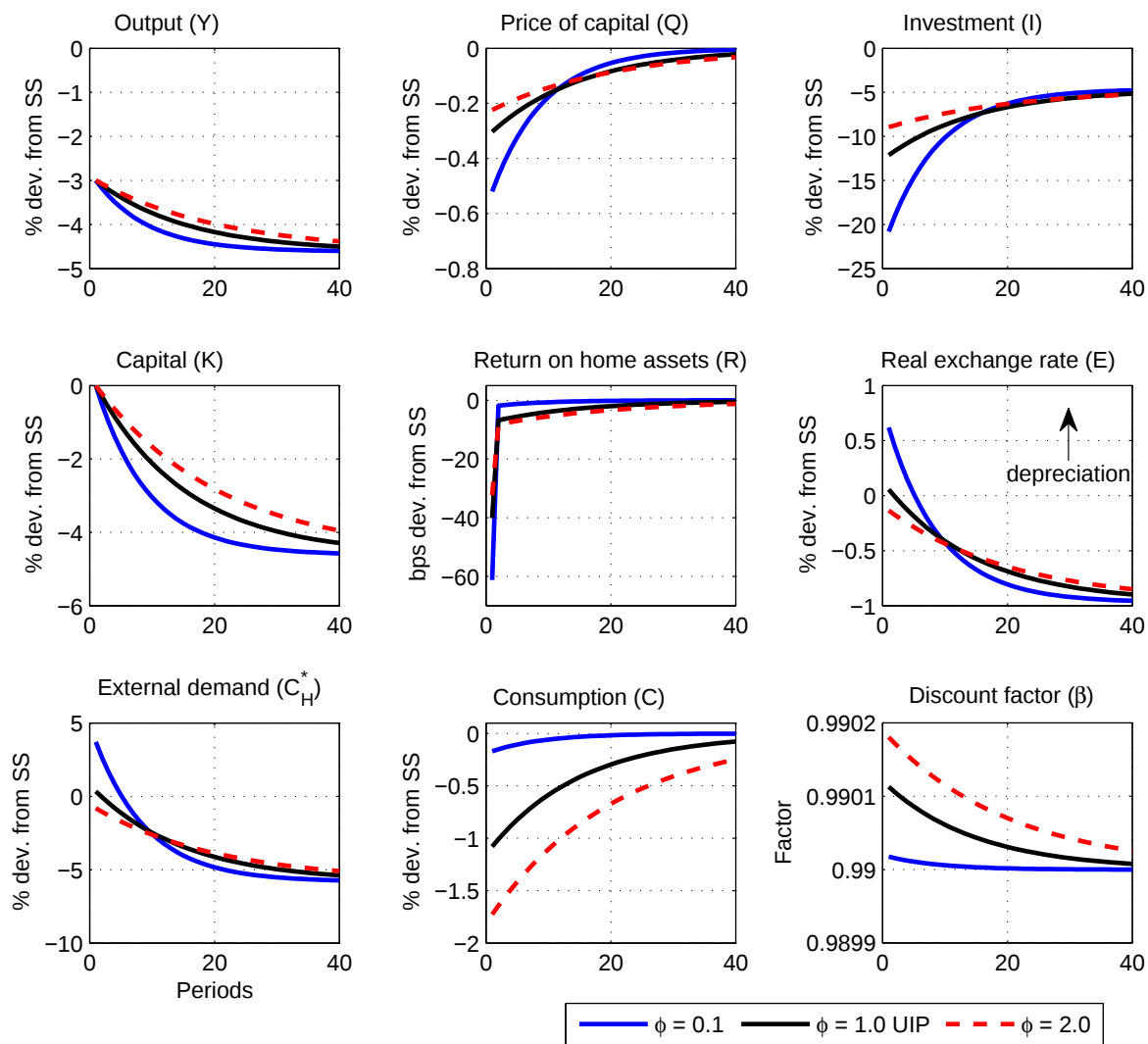
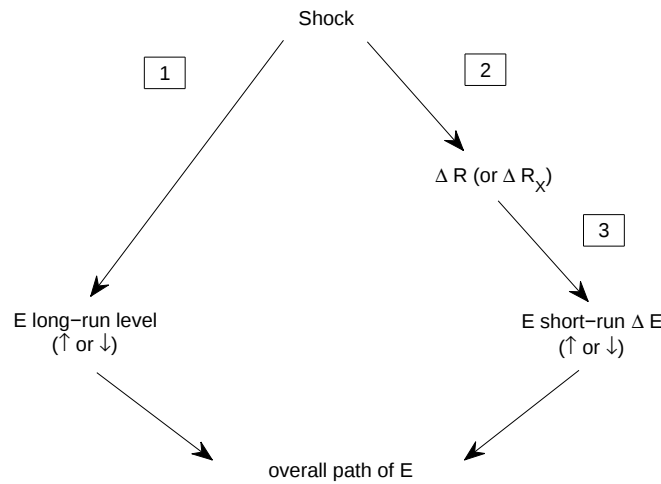


Figure 5: Exchange rate determination



here in figure 5. Consider the first arrow. The long run level of the exchange rate is appreciated $\hat{E} \downarrow$. The shock permanently lowers the supply of the home good and so, in order to clear goods markets in the long run, the relative price of home goods must rise and hence the real exchange rate appreciates.

Consider the second arrow. Because capital is slow to adjust (both because it is predetermined and because there is a cost of adjustment ξ) the fall in productivity causes the marginal product of capital to fall as well. Put differently, because capital is slow to adjust, there is excess supply of capital after the shock and so the price of capital falls, causing holders of home assets to suffer a loss.

The third arrow then follows from the second arrow. The return on home assets falls and so in equilibrium the exchange rate must be appreciating along the adjustment path in order to equalise the common currency returns of home and foreign assets.

The overall path of the exchange rate then follows from these short and long run effects. Because both the short and long run effects are in the same direction (an appreciation $\downarrow$), the exchange rate initially undershoots its long run level. Whether the exchange

rate initially jumps (and the direction of this jump) is then determined by the relative sizes of the short and long run effects, as section 2.5 illustrated. In the simulations, we consider three values for $\phi \in \{0.1, 1, 2.0\}$. Recall from section 2.5 that lowering ϕ does not change the long run level of the exchange rate $\tilde{E}$ but it augments the per-period appreciation required to compensate for the fall in the home asset's return. Consequently, when $\phi = 0.1$ and $\phi = 1.0$ (UIP), the exchange rate undergoes such a large cumulative per-period appreciation along the adjustment path that it initially depreciates. On the other hand, when $\phi = 2.0$, the per-period appreciation is so small that the exchange rate does not initially depreciate - it initially appreciates.

We have been describing the exchange rate movement from a *reduced form* view (i.e. by describing how the exchange rate must behave in order to satisfy equilibrium conditions). The causal *structural form* view is straightforward. Because the return on home assets falls, investors immediately substitute out of home assets in favour of holding foreign assets that yield a higher return. This causes financial outflows and places downward pressure on the exchange rate until it is sufficiently under-valued (relative to its long run equilibrium level) such that investors are again willing to hold onto home assets. This is the point where the subsequent per-period appreciation of the exchange rate raises the common currency return on home assets enough such that investors are again indifferent between home and foreign assets. When ϕ is small, investors are only indifferent between the two assets when the common currency return on home assets rises by more, and so the financial outflows do not stop until the exchange rate is so under-valued initially that it actually depreciates. However, this initial depreciation is very small. We explain the reason for this below in section 4.3.

Finally, the path of external demand (C_H^*) is simply determined by the exchange rate. Home consumption (C) falls initially in response to the fall in the interest rate and

then recovers, as standard Euler dynamics predict. The endogenous discount factor (β) is consistent with the path of consumption since it initially rises, indicating a fall in impatience, which compensates consumers for the initial fall in consumption with the expectation that consumption will grow in subsequent periods.

In Appendix 4 we show that the implications of a temporary shock are qualitatively similar.

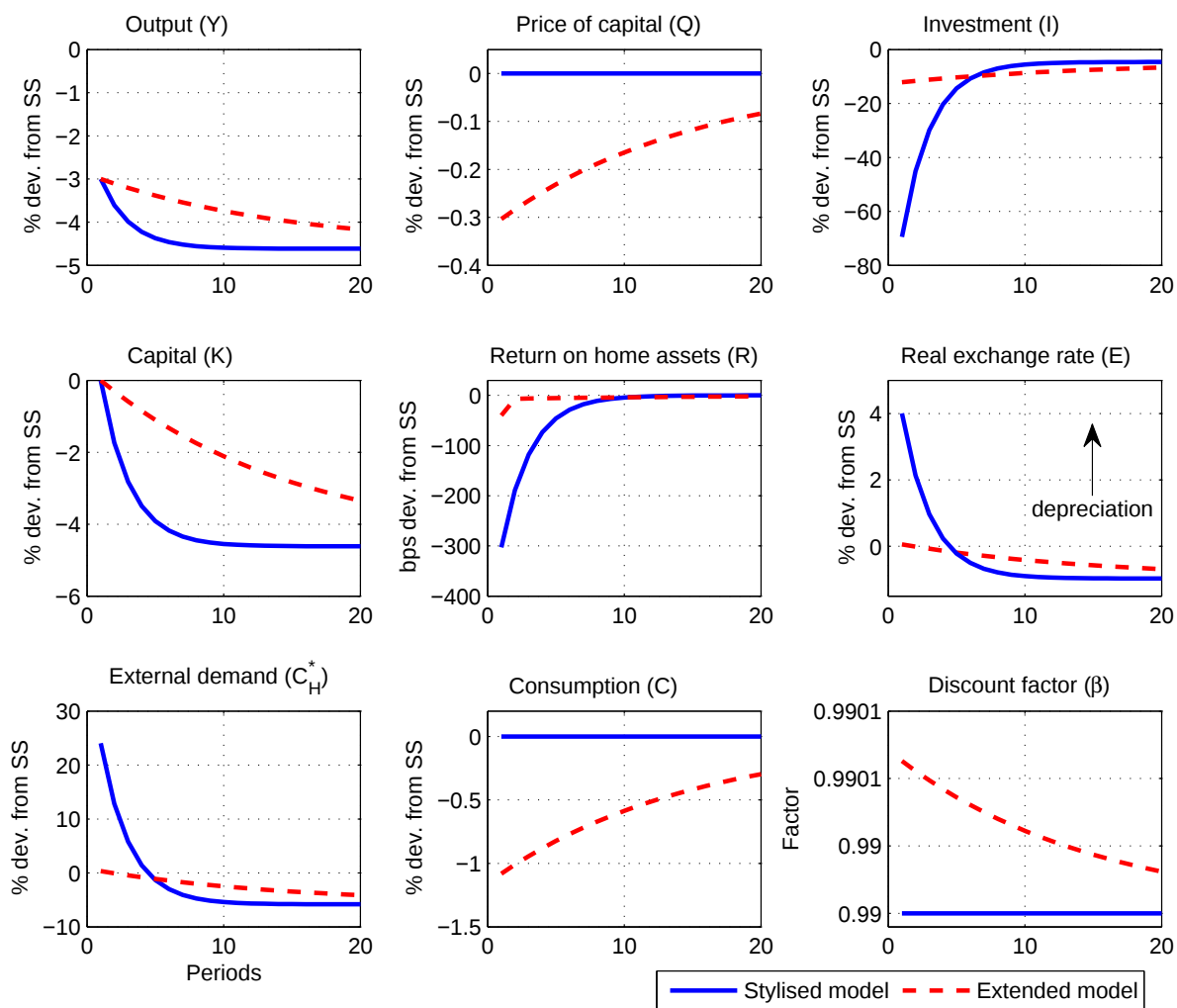
4.3 The effect of forward-looking consumers and Tobin's Q

We conclude this Chapter by describing the effect of extending the model to include forward-looking consumers and Tobin's Q . Figure 6 plots simulations of the same 3% fall in productivity in the stylised model of section 2 (blue lines) and in the full model (red lines) for $\phi = 1$ (UIP). Both models exhibit qualitatively similar responses to the shocks, but the magnitudes of the responses can vary significantly.

Consider, first, the response of investment. In the full model there is a cost of capital adjustment ξ and so firms prefer to smooth the decumulation of capital over time. Thus investment falls moderately initially and recovers much more gradually. As a result, the adjustment of capital and, in turn, output, is also more gradual in the full model. On the other hand, in the absence of adjustment costs in the stylised model, investment shoots down and the capital stock falls much more rapidly to its new long-run level. The long-run level of capital in both models is the same because it is pinned down by the same exogenous technology shock.

Because the adjustment of capital is more gradual in the full model, it has to be compensated for by changes in the price of capital Q . Notice how Q initially jumps down and then recovers. Q initially jumps down because the demand for capital goods

Figure 6: The effect of adding forward-looking consumers and Tobin's Q



falls but the capital stock is slow to decumulate (hence giving rise to excess supply of capital). The price Q falls until the point where it is sufficiently below its long run level that capital goods producers are willing to start raising investment. This is the point where the subsequent upward rise in Q generates enough of a gain on holding capital to compensate for the fall in productivity and the cost of adjusting the stock of capital (this is analogous to the explanation of exchange rate under-valuation above). Hence Q initially falls and then rises again as investment in capital recovers (the excess supply of capital clears).

Crucially, because the burden of adjustment falls on Q as well as on the rate of return R in the full model, the rate of return R does not have to fall by as much. Furthermore, because Q rises along the adjustment path, this creates a capital gain on holding home assets, which means that the return on home assets recovers more quickly after the shock. Hence, in the full model, the real interest rate falls by less and recovers more quickly.

Thus the exchange rate does not need to experience as large a cumulative per-period appreciation in order to ensure no-arbitrage in international asset markets. And because the long-run level of the exchange rate is the same under both models (pinned down by the exogenous technology shock), then a smaller short-run appreciation of the exchange rate also implies a smaller initial depreciation.

Thus we see in the middle-right panel of figure 6 that, in the full model, the exchange rate initially depreciates by much less (less than 10 bps, compared to almost 400 bps in the stylised model without Q), but it then converges onto the same long-run level as in the stylised model. In summary, adding the price of capital Q means that the rate of return R does not fluctuate as much after shocks and so accordingly the burden of adjustment on the exchange rate is smaller as well.

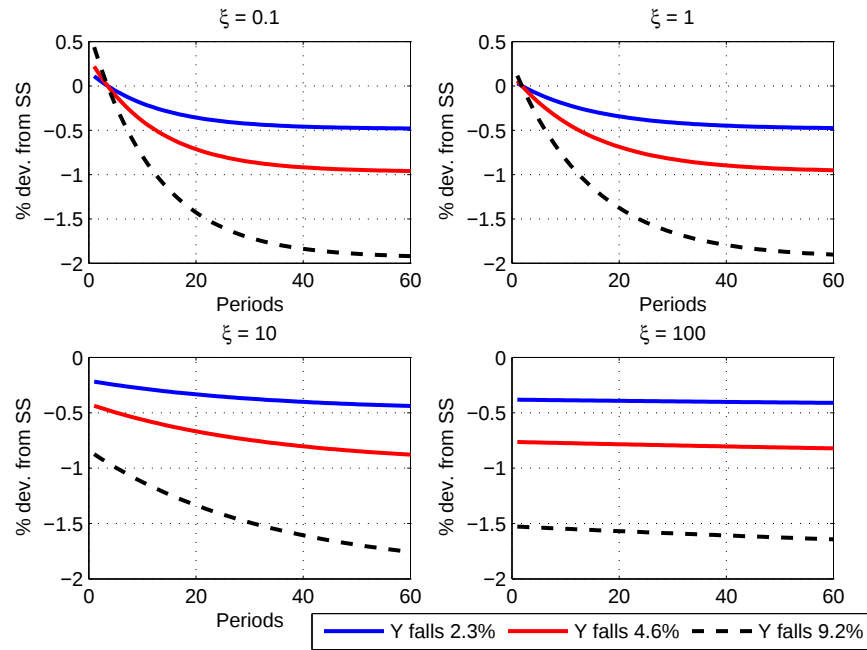
This means that a model like the one in this Chapter, which relies on a condition similar to UIP to pin down exchange rates, generates a small amount of exchange rate volatility, especially in the presence of sensible features like forward-looking consumers and a moving price of capital. The later Chapters in this thesis demonstrate how features that augment the UIP condition increase exchange rate volatility.

Turning to the last three panels in figure 6: the difference in external demand for home goods is explained by the difference in exchange rate behaviour. Under the full model, aggregate home consumption is free to fall in response to the shock. However, the effect of this is offset by the fact that investment falls by less in the full model, which means that the overall domestic demand for home goods is roughly the same under both models.

Sensitivity analysis

The conclusion that this baseline model with UIP ($\phi = 1$) generates a small degree of exchange rate volatility is clearly dependent on numerical parameterisation and is conditional on the size of the shock. A large shock would obviously generate a large jump in exchange rates. Here, we perform a brief sensitivity analysis to show that our conclusion above is robust to choosing different values of ξ (the capital adjustment cost) for reasonably sized technology shocks. We judge the size of a shock based on its effect on output in the long run. The higher is ξ , the more that the price of capital falls after a negative shock and hence the more that the burden of adjustment is relieved from the home interest rate and the exchange rate.

Figure 7 shows that, for a small or moderate level of adjustment costs ($\xi = 0.1$ and $\xi = 1$), even a very large shock (where output falls by close to 10%) still leads to very

Figure 7: Sensitivity analysis with respect to ξ and the size of shock

small initial jumps in the exchange rate (less than half a percentage point). When adjustment costs are higher ($\xi = 10$ and $\xi = 100$), the initial jumps become larger but are still small compared with the changes in output. When $\xi = 10$, the largest jump is still smaller than 1% and when $\xi = 100$, the largest jump is barely larger than 1.5%, which is arguably small, given the implausibly large fall in output of almost 10%.

This comes short of the kind of exchange rate volatility observed in figure 1 of the Introduction. That figure shows that in the 2008 crisis, real exchange rates fell by around 20%, but output only fell by around 5% at most in those countries. In the third quarter of 2013, we observed falls in real exchange rates of India (5%), Indonesia (10%), and Turkey (6%), without there being any falls in output. Of course, we never set out to produce a model that can explain every observed change in exchange rates, but set against these recent movements in exchange rates, this does tentatively point to the conclusion that this baseline model generates too little exchange rate volatility.

Other real rigidities are necessary in order to generate greater volatility.

Another way to make the point that the exchange rate volatility here is low is to compare the second-order moments of this model with the data. In the top panel of table 2, we report the standard deviations of bilateral real exchange rates as estimated by Chari, Kehoe and McGrattan (2002) using quarterly data from 1973 to 2000. In the bottom panel, we report the theoretical standard deviations from our model with only temporary productivity shocks²⁰. The columns refer to different values of the capital adjustment cost ξ and the rows refer to different sizes of the innovation to technology (measured in terms of the shock's contemporaneous effect on output).

Table 2 shows that, even for very large shocks (in terms of their effect on output), the standard deviation produced by this model is still very small compared to the data. Of course, there are other shocks captured by the data, not just technology shocks. However, the empirical literature we previously cite (Chakraborty, 2009; Peersman and Straub, 2004) claims that exogenous shocks to productivity account for a large proportion of economic fluctuations and so they should account for a reasonable share of real exchange rate fluctuations as well²¹. This is something this baseline model does not capture.

5 Concluding remarks

This Chapter has two purposes. The first purpose was to elaborate on the well-established framework, outlined in section 4.1 of the Introduction, that we use to account for exchange rate movements in this thesis. The basic point is that jumps in the

²⁰We assume a simple AR(1) structure for the technology shock A with a coefficient of 0.93, following Peersman and Straub (2004).

²¹Chakraborty and Otsu (2013) claim that the efficiency wedge accounts for around 98% of output fluctuations in Brazil and Russia in the 2000s.

Table 2: Comparing standard deviations of the real exchange rate

Estimated standard deviation of E					
country relative to US					
Austria	Denmark	Finland	France	Germany	Italy
7.93	8.00	7.71	7.95	8.06	7.80
Netherlands	Norway	Spain	Switzerland	UK	Europe
7.99	6.08	8.42	8.83	7.89	7.52
Source: Chari, Kehoe and McGrattan (2002)					
Model-derived standard deviation of E					
		ξ			
		0.1	1	10	100
ΔY on impact	0.1%	0.07	0.06	0.07	0.08
	1%	0.66	0.63	0.66	0.77
	3%	1.98	1.90	1.98	2.31
	5%	3.31	3.16	3.30	3.85
	7%	4.63	4.43	4.62	5.39

exchange rate can arise from differences between its long-run level and its cumulative short-run per-period adjustment. Asset equilibrium conditions typically pin down the per-period adjustment of the exchange rate, while goods market clearing conditions determine its final level. This was examined in section 2.

The second and main purpose of this Chapter was to apply this framework to our baseline model. In this model, the basic real rigidity of slow capital adjustment gives rise to exchange rate volatility because it causes the real return on home assets to vary after productivity shocks, hence leading to financial inflows or outflows that affect the exchange rate. For instance, a fall in aggregate productivity causes the return on home assets to fall because capital cannot decumulate to its new long run level immediately. Investors substitute away from holding home assets, causing financial outflows that put downward pressure on the exchange rate until it is so under-valued that investors are again willing to hold onto home assets. This is where the subsequent appreciation of the exchange rate to its long-run equilibrium level equalises the common currency return

on home and foreign assets. Our model is thus a real analogue to that of Dornbusch (1976) and the monetary models that have followed (e.g. Gali and Monacelli, 2005).

However, in this baseline model, the transmission channel described above generates little exchange rate volatility. This is because reasonably sized technology shocks generate small differences between the returns on home and foreign assets, especially in the presence of a moving price of capital. Hence the burden of adjustment on the exchange rate is dampened and its initial jump after shocks is accordingly muted. Other real rigidities need to be added to magnify the effect of real shocks on the exchange rate.

In the following Chapters, we develop extensions to the baseline model that generate greater exchange rate volatility. In Chapter 2, we introduce imperfect asset substitutability and, in Chapter 3, we introduce a banking sector and financial frictions.

References

- [1] Aghion, Philippe, Philippe Bacchetta, & Abhijit Banerjee. 2004. A corporate balance-sheet approach to currency crises. *Journal of Economic Theory* 119 (1): 6—30.
- [2] Amano, Robert & Simon van Norden, 1993. A forecasting equation for the Canada-US dollar exchange rate. In *The Exchange Rate and the Economy*. Proceedings of a conference held at the Bank of Canada, June 1992.
- [3] Bailliu, Jeannine & Michael R. King. 2005. What drives movements in exchange rates?. *Bank of Canada Review* 2005 (Autumn): 27—39. Bank of Canada.
- [4] Baxter, Marianne. 1994. Real exchange rates and real interest differentials: have we missed the business-cycle relationship?. *Journal of Monetary Economics* 33 (1): 5—37.
- [5] Burnside, Craig, Martin Eichenbaum & Sergio Rebelo. 2008. Currency crisis models. In *The New Palgrave Dictionary of Economics* (2nd ed.), edited by Steven N. Durlauf & Lawrence E. Blume. Palgrave Macmillan.
- [6] Cespedes, Luis F., Roberto Chang, & Andres Velasco. 2004. Balance sheets and exchange rate policy. *American Economic Review* 94 (4): 1183—93.

-
- [7] ———. 2012. Financial intermediation, exchange rates, and unconventional policy in an open economy. NBER Working Papers 18431. National Bureau of Economic Research.
- [8] Chakraborty, Suparna. 2009. The boom and the bust of the Japanese economy: a quantitative look at the period 1980-2000. *Japan and the World Economy* 21 (1): 116—131, January.
- [9] Chakraborty, Suparna & Otsu Keisuke. 2013. Business cycle accounting of the BRIC economies. *The B.E. Journal of Macroeconomics* 13 (1): 1—33, September.
- [10] Chari, Varadarajan V., Patrick J. Kehoe & Ellen R. McGrattan. 2002. Can sticky price models generate volatile and persistent real exchange rates?. *Review of Economic Studies* 69 (3): 533—63.
- [11] Claus, Iris. 2007. The effects of bank lending in an open economy. *Journal of Money, Credit and Banking* 39 (5): 1213—48.
- [12] ———. 2011. The effects of asymmetric information between borrowers and lenders in an open economy. *Journal of International Money and Finance* 30 (5): 796—816.
- [13] Cooley, Thomas F., Gary D. Hansen, & Edward C. Prescott. 1995. Equilibrium business cycles with idle resources and variable capacity utilization. *Economic Theory* 6 (1): 35—49.
- [14] Crucini, Mario J., Mototsugu Shintani, & Takayuki Tsuruga. 2013. Do sticky prices increase real exchange rate volatility at the sector level?. *European Economic Review* 62: 58—72.
- [15] Dornbusch, Rudiger. 1976. Expectations and exchange rate dynamics. *Journal of Political Economy* 84 (6): 1161—76.
- [16] Frenkel, Jacob A., 1976. A monetary approach to the exchange rate: doctrinal aspects and empirical evidence. *Scandinavian Journal of Economics* 78 (2): 200—24.
- [17] Gali, Jordi & Tommaso Monacelli. 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies* 72: 707—34.
- [18] Gertler, Mark, Simon Gilchrist & Fabio Natalucci. 2007. External constraints on monetary policy and the financial accelerator. *Journal of Money, Credit and Banking* 39 (2—3): 295—330.
- [19] Hayashi, Fumio & Edward C. Prescott. 2002. The 1990s in Japan: a lost decade. *Review of Economic Dynamics* 5 (1): 206—35, January.

-
- [20] Kuralbayeva, Karlygash & David Vines. 2009. The process by which the dollar will fall: the effect of forward-looking consumers. CEPR Discussion Papers 7325. Centre for Economic Policy Research.
- [21] Krugman, Paul. 1979. A model of balance-of-payments crises. *Journal of Money, Credit and Banking* 11 (3): 311—25.
- [22] ———. 1999. Balance sheets, the transfer problem, and financial crises. *International Tax and Public Finance* 6 (4): 459—72.
- [23] Kydland, Finn E. & Edward C. Prescott. 1982. Time to build and aggregate fluctuations. *Econometrica* 50 (6): 1345—70.
- [24] Lane, Philip R. 2001. The new open macroeconomics: a survey. *Journal of International Economics* 54 (2): 235—66.
- [25] Lucas, Robert E. 1982. Interest rates and currency prices in a two-country world. *Journal of Monetary Economics* 10 (3): 335—59.
- [26] Luk, Sheung Kan & David Vines. 2011. Financial-friction macroeconomics with highly leveraged financial institutions. CEPR Discussion Papers 8576. Centre for Economic Policy Research.
- [27] Meese, Richard A. & Kenneth Rogoff. 1983. Empirical exchange rate models of the seventies: do they fit out of sample?. *Journal of International Economics* 14(1-2): 3—24.
- [28] ———. 1988. Was it real? The exchange rate-interest differential relation over the modern floating-rate period. *Journal of Finance* 43 (4): 933—48.
- [29] Meredith, Guy. 2007. Debt dynamics and global imbalances: some conventional views reconsidered. IMF Working Paper WP/07/4. International Monetary Fund, Washington, D.C., January 2007.
- [30] Obstfeld, Maurice. 1986. Rational and self-fulfilling balance-of-payments crises. *American Economic Review* 76 (1): 72—81.
- [31] Obstfeld, Maurice & Kenneth Rogoff. 1995. Exchange rate dynamics redux. *Journal of Political Economy* 103 (3): 624—60, June.
- [32] ———. 2001. The six major puzzles in international macroeconomics: is there a common cause?. In *NBER Macroeconomics Annual 1990* (15), edited by Ben S. Bernanke & Kenneth Rogoff. Cambridge, MA: NBER.
- [33] Peersman, Gert & Roland Straub. 2004. Technology shocks and robust sign restrictions in a euro area SVAR. Working Paper Series No. 373, European Central Bank, July.

- [34] Plosser, Charles I. 1989. Understanding real business cycles. *The Journal of Economic Perspectives* 3 (3): 51—78.
- [35] Sa, Filipa & Francesca Viani. 2013. Shifts in portfolio preferences of international investors: an application to sovereign wealth funds. *Review of International Economics* 21 (5): 868—85.
- [36] Schmitt-Grohe, Stephanie & Martin Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61 (1): 163—85.
- [37] Stockman, Alan C. 1980. A theory of exchange rate determination. *Journal of Political Economy* 88 (4): 673—98, August.
- [38] Taylor, Mark P., David A. Peel, & Lucio Sarno. 2001. Nonlinear mean-reversion in real exchange rates: toward a solution to the purchasing power parity puzzles. *International Economic Review* 42 (4): 1015—42.
- [39] Ueda, Kozo. 2012. Banking globalization and international business cycles: cross-border chained credit contracts and financial accelerators. *Journal of International Economics* 86 (1): 1—16.

Appendix

1 Deriving the condensed log-linearised model

The equations (1), (3), (2), (5), (6), (7), (8), (9), (10), (11), (12), and (13) describe the equilibrium dynamics of the variables $\{Y_t, K_t, R_t, I_t, C_{Ht}, C_{Ft}, P_t, P_{Ht}, P_{Ft}, E_t, C_{Ht}^*, P_{Ht}^*\}_{t=0}^{\infty}$ given an exogenous process for A_t .

Log-linearising these equations around the steady state gives us:

$$\hat{Y}_t = \hat{A}_t + \alpha \hat{K}_t \quad (47)$$

$$\hat{K}_{t+1} = (1 - \delta) \hat{K}_t + \delta \hat{I}_t \quad (48)$$

$$\hat{R}_t = \frac{\alpha \beta \bar{Y}}{\bar{K}} (\hat{Y}_t - \hat{K}_t) \quad (49)$$

$$\hat{C}_{Ht} = -\eta (\hat{P}_{Ht} - \hat{P}_t) \quad (50)$$

$$\hat{C}_{Ft} = -\eta (\hat{P}_{Ft} - \hat{P}_t) \quad (51)$$

$$\hat{C}_{Ht}^* = -\eta (\hat{P}_{Ht}^*) \quad (52)$$

$$\hat{P}_t = \gamma \hat{P}_{Ht} + (1 - \gamma) \hat{P}_{Ft} \quad (53)$$

$$\hat{P}_{Ft} = \hat{E}_t \quad (54)$$

$$\hat{P}_{Ht}^* = \hat{P}_{Ht} - \hat{E}_t \quad (55)$$

$$\hat{P}_{Ht} = 0 \quad (56)$$

$$\bar{Y}\hat{Y}_t = \gamma \bar{C}\hat{C}_{Ht} + (1 - \gamma) \bar{C}\hat{C}_{Ht}^* + \bar{I}\hat{I}_t \quad (57)$$

$$\mathcal{E}_t(\hat{R}_{t+1}) = \phi \mathcal{E}_t(\hat{R}_{t+1}^* + \hat{E}_{t+1} - \hat{E}_t) \quad (58)$$

We treat R^* as constant and exogenous. Combining equations (54) to (56) with (50) gives $\hat{C}_{Ht} = \eta(1 - \gamma)\hat{E}_t$ and with (52) gives $\hat{C}_{Ht}^* = \eta\hat{E}_t$. Substituting these expressions into (57) gives us equation (14). Substituting (49) into (58) gives us equation (15). Equation (48) is the same as equation (16).

2 Deriving the time path of the exchange rate

The state space solution of the model is given by:

$$\begin{bmatrix} \hat{I}_t \\ \hat{E}_t \end{bmatrix} = \begin{bmatrix} \mathbf{i}_1 & \mathbf{i}_2 \\ \mathbf{e}_1 & \mathbf{e}_2 \end{bmatrix} \begin{bmatrix} \tilde{A} \\ \hat{K}_t \end{bmatrix}$$

where (solved by method of undetermined coefficients)

$$\begin{aligned} \mathbf{i}_1 &= \frac{\alpha\beta}{2\phi\bar{K}(1-\alpha)\delta\bar{Y}^{\frac{1-\alpha}{\alpha}}} (\mathbf{Z} + \sqrt{\mathbf{Z}^2 + \mathbf{Q}}) \quad , \quad \mathbf{e}_1 = \frac{2Y^{\frac{1}{\alpha}}}{\bar{Q}} \left(2\phi\bar{K}^{\frac{(1-\alpha)}{\alpha\beta}} - (\mathbf{Z} + \sqrt{\mathbf{Z}^2 + \mathbf{Q}}) \right) \\ \mathbf{i}_2 &= 1 - \frac{1}{2\delta\bar{Y}^{\frac{1}{\alpha}}} (\mathbf{Z} + \sqrt{\mathbf{Z}^2 + \mathbf{Q}}) \quad , \quad \mathbf{e}_2 = (1 - \alpha) \left(\frac{2Y^{\frac{1}{\alpha}}}{\mathbf{Z} + \sqrt{\mathbf{Z}^2 + \mathbf{Q}}} - \frac{\alpha\beta\bar{Y}}{\phi\bar{K}} \right) \end{aligned}$$

where

$$\begin{aligned}\mathbf{Z} &= \frac{\phi\bar{K}}{\alpha\beta} \left(\delta\bar{Y}^{\frac{1-\alpha}{\alpha}} - \alpha \right) - \eta(1-\alpha)(1-\gamma^2) \left(\bar{Y} - \delta\bar{Y}^{\frac{1}{\alpha}} \right) \\ \mathbf{Q} &= 4\eta\phi\bar{K} \frac{(1-\alpha)}{\alpha\beta} (1-\gamma^2) \bar{Y}^{\frac{1}{\alpha}} \left(1 - \delta\bar{Y}^{\frac{1-\alpha}{\alpha}} \right)\end{aligned}$$

From equation (16), we can show that the evolution of capital is given by $\widehat{K}_{t+1} = \delta\mathbf{i}_1\tilde{A} + (1-\delta+\delta\mathbf{i}_2)\widehat{K}_t$ and so the time path of the capital stock is given by $\widehat{K}_t = \frac{\mathbf{i}_1\tilde{A}}{1-\mathbf{i}_2} \left(1 - (1-\delta+\delta\mathbf{i}_2)^t \right)$. Furthermore, we know that the capital stock at the new steady state is given by $\widetilde{K} = \frac{\tilde{A}}{1-\alpha}$ and so we can back out the time period $\tilde{t}$ at which the new steady state is reached. This is given by

$$\begin{aligned}\tilde{t} &= \frac{\log \left(1 - \frac{1-\mathbf{i}_2}{\mathbf{i}_1(1-\alpha)} \right)}{\log(1-\delta+\delta\mathbf{i}_2)} \\ &= \log_{1-\delta+\delta\mathbf{i}_2} \left(1 - \frac{1-\mathbf{i}_2}{\mathbf{i}_1(1-\alpha)} \right) \quad (\text{change of log base rule})\end{aligned}$$

Using our expression for the time path of capital in equation (15), we can show that

$$\begin{aligned}\phi\mathcal{E}_t(\widehat{E}_{t+1} - \widehat{E}_t) &= \frac{\alpha\beta\bar{Y}}{\bar{K}} \left(\tilde{A} - (1-\alpha)\widehat{K}_{t+1} \right) \\ \mathcal{E}_t(\widehat{E}_{t+1} - \widehat{E}_t) &= \frac{\alpha\beta\bar{Y}}{\phi\bar{K}}\tilde{A} - \frac{\alpha\beta\bar{Y}}{\phi\bar{K}}(1-\alpha)\widehat{K}_{t+1} \\ &= \frac{\alpha\beta\bar{Y}}{\phi\bar{K}}\tilde{A} - \frac{\alpha\beta\bar{Y}(1-\alpha)}{\phi\bar{K}} \frac{\mathbf{i}_1\tilde{A}}{(1-\mathbf{i}_2)} + \frac{\alpha\beta\bar{Y}(1-\alpha)}{\phi\bar{K}} \frac{\mathbf{i}_1\tilde{A}}{(1-\mathbf{i}_2)} (1-\delta+\delta\mathbf{i}_2)^{t+1} \\ &\equiv \mathbf{\Gamma}(t+1)\end{aligned}$$

We know that $\widehat{E}_0 = \mathcal{E}_0(\widehat{E}_1 - \mathbf{\Gamma}(1))$ but this alone does not solve for $\widehat{E}_0$ because it depends on the expected future level $\widehat{E}_1$. We need to iterate this equation forward until we get to the time period $\tilde{t}-1$ since the exchange rate at time $\tilde{t}$ is known (it is the new

long-run level $\tilde{E}$). That is

$$\begin{aligned}
 \hat{E}_0 &= \hat{E}_1 - \Gamma(1) \\
 \hat{E}_1 &= \hat{E}_2 - \Gamma(2) \\
 &\dots \\
 \hat{E}_{\tilde{t}-2} &= \hat{E}_{\tilde{t}-1} - \Gamma(\tilde{t}-1) \\
 \hat{E}_{\tilde{t}-1} &= \hat{E}_{\tilde{t}} - \Gamma(\tilde{t})
 \end{aligned}$$

and so it becomes clear that $\hat{E}_0$ depends on the **integral of expected exchange rate changes**

$$\begin{aligned}
 \hat{E}_0 &= \hat{E}_{\tilde{t}} - \mathcal{E}_0 \left(\sum_{j=1}^{\tilde{t}} \Delta \hat{E}_j \right) \\
 &= \tilde{E} - \mathcal{E}_0 \left(\sum_{j=1}^{\tilde{t}} \Gamma(j) \right)
 \end{aligned}$$

$$\begin{aligned}
 &\tilde{E} - \mathcal{E}_0 \left(\sum_{j=1}^{\tilde{t}} \frac{\alpha \beta \bar{Y} (1-\alpha)}{\phi \bar{K}} \frac{\mathbf{i}_1 \tilde{A}}{(1-\mathbf{i}_2)} (1-\delta + \delta \mathbf{i}_2)^j \right) \\
 &= \tilde{E} - \frac{\alpha \beta \bar{Y} (1-\alpha) \mathbf{i}_1 \tilde{A}}{\phi \bar{K} (1-\mathbf{i}_2)} \frac{(1-\delta + \delta \mathbf{i}_2)}{\delta (1-\mathbf{i}_2)} \left(1 - (1-\delta + \delta \mathbf{i}_2)^{\tilde{t}} \right)
 \end{aligned}$$

Recalling that $\tilde{t} = \log_{1-\delta+\delta \mathbf{i}_2} \left(1 - \frac{1-\mathbf{i}_2}{\mathbf{i}_1(1-\alpha)} \right)$ and using the fact that $(1-\mathbf{i}_1)(1-\alpha)\delta(1-\mathbf{i}_2) = \mathbf{i}_1(1-\alpha)(1-\delta+\delta \mathbf{i}_2)$ ²², the above expression simplifies to²³

$$\hat{E}_0 = \tilde{E} - \frac{\tilde{A} \alpha \beta \bar{Y}}{\delta \phi \bar{K}} \left(\frac{1}{\mathbf{i}_1(1-\alpha)} - \delta \right)$$

²²This is a derivation arrived at from using the method of undetermined coefficients to solve the state space solution above.

²³The full solution for $\hat{E}_0$ is given by $\hat{E}_0 = \tilde{E} - \frac{\tilde{A} \alpha \beta \bar{Y}}{\delta \phi \bar{K}} \left(\frac{2\phi \bar{K} \delta \bar{Y}^{\frac{1-\alpha}{\alpha}}}{\alpha \beta (\mathbf{Z} + \sqrt{\mathbf{Z}^2 + \mathbf{Q}})} - \delta \right)$.

which is the expression (17) seen in section 2.5.

3 Equilibrium dynamics in the Baseline Model

This Appendix characterises the equilibrium dynamics of the model in a way analogous to that in section 2.6. This Appendix shows that the model can be collapsed into a system similar to the stylised framework of the section 2.

This is a perfect foresight model and so the rational expectation equilibrium can be represented by a standard state-space solution that expresses each endogenous variable as a function of the predetermined and exogenous variables.

$$\begin{bmatrix} \hat{C}_t \\ \hat{\lambda}_t \\ \hat{\sigma}_t \\ \hat{I}_t \\ \hat{Q}_t \\ \hat{E}_t \\ \hat{K}_{t+1} \end{bmatrix} = \begin{bmatrix} \mathbf{c}_1 & \mathbf{c}_2 \\ \mathbf{l}_1 & \mathbf{l}_2 \\ \mathbf{s}_1 & \mathbf{s}_2 \\ \mathbf{i}_1 & \mathbf{i}_2 \\ \mathbf{q}_1 & \mathbf{q}_2 \\ \mathbf{e}_1 & \mathbf{e}_2 \\ \mathbf{k}_1 & \mathbf{k}_2 \end{bmatrix} \begin{bmatrix} \hat{A}_t \\ \hat{K}_t \end{bmatrix} \quad (59)$$

Including forward-looking consumption, the two Lagrange multipliers associated with the endogenous discount factor, and Tobin's Q means that this system has four more jump variables than the stylised framework in section 2. This makes a complete analytical solution to the system less tractable. However, it is possible to exploit some features of the model in order to diagrammatically characterise the equilibrium saddle-path of the economy. We aim to characterise the equilibrium dynamics of the exchange rate as a function of the technology shock and the predetermined stock of capital. That is, we

eliminate all variables except for $\widehat{E}$ and $\widehat{K}$. This is a similar technique to that applied by Cespedes, Chang and Velasco (2004).

First, we exploit the fact that the endogenous discount factor (equations (44) to (46)) induces stationarity in the model. This means we can infer the signs of the coefficients in the transition functions for consumption and investment

$$\widehat{C}_t = \mathbf{c}_1 \widetilde{A} + \mathbf{c}_2 \widehat{K}_t \quad (60)$$

$$\widehat{I}_t = \mathbf{i}_1 \widetilde{A} + \mathbf{i}_2 \widehat{K}_t \quad (61)$$

Because the system is determinate, we know that $\mathbf{c}_1, \mathbf{i}_1 > 0$ (consumption and investment rise with productivity), and $\mathbf{c}_2, \mathbf{i}_2 < 0$ (when capital is above steady-state, investment falls below steady-state to reduce the capital stock and consumption also falls because the current period rate of return on capital falls)²⁴.

Next, we use equation (43) to eliminate $\widehat{Q}$ by expressing it as a function of $\widehat{A}$ and $\widehat{K}$

$$\widehat{Q}_t = \xi \delta \mathbf{i}_1 \widetilde{A} + \xi \delta (\mathbf{i}_2 - 1) \widehat{K}_t \quad (62)$$

Substituting (60), (61), and (62) into the remaining equations in the condensed model (i.e. equations (40), (41), and (42)) gives us three equations. First, there is an equation describing the equilibrium relationship between $\widehat{K}$ and $\widehat{E}$ within any period

$$\widehat{E}_t \left(\overline{C}_H \eta (1 - \gamma) + \overline{C}^*_{H\mu} \right) = \underbrace{\widetilde{A} \left(\overline{Y} - \overline{C}_H \mathbf{c}_1 - \overline{I} \frac{1 - \mathbf{i}_2}{1 - \alpha} \right)}_{\text{sign ambiguous}} + \underbrace{\widehat{K}_t \left(\alpha \overline{Y} - \overline{C}_H \mathbf{c}_2 - \overline{I} \mathbf{i}_2 \right)}_{> 0} \quad (63)$$

²⁴This can be verified numerically.

Second, there is an equation describing the rate of change of capital

$$\Delta \widehat{K}_{t+1} = \underbrace{\widetilde{A} \delta \frac{1 - \mathbf{i}_2}{1 - \alpha}}_{> 0} + \underbrace{\widehat{K}_t \delta (\mathbf{i}_2 - 1)}_{< 0} \quad (64)$$

Third, there is an equation describing the rate of change of the exchange rate

$$\phi \Delta \widehat{E}_{t+1} = \widetilde{A} \Omega_A + \widehat{K}_t \Omega_K \quad (65)$$

where

$$\begin{aligned} \Omega_A &\equiv -\xi \delta \mathbf{i}_1 + (1 - \delta \mathbf{i}_1 (1 - \alpha)) \left(1 - \frac{1 - \delta}{R} (1 - \xi \delta \mathbf{i}_1) \right) > 0 \text{ for sufficiently small } \delta \\ \Omega_K &\equiv \xi \delta \mathbf{i}_1 - (1 - \alpha) (1 - \delta \mathbf{i}_1 (1 - \alpha)) \left(1 - \frac{1 - \delta}{R} (1 - \xi \delta \mathbf{i}_1) \right) < 0 \text{ for sufficiently small } \delta \end{aligned}$$

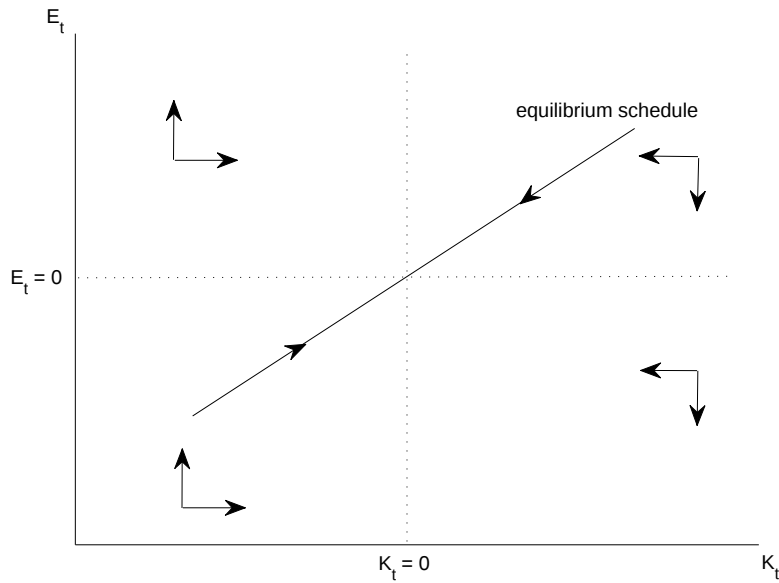
The entire system collapses to three equations ((63), (64), and (65)), that can be represented in $(\widehat{K}_t, \widehat{E}_t)$ space. We illustrate this system in figure 8. The economy is always on the equilibrium schedule represented by equation (63) which is unambiguously upward-sloping: as capital increases, current period production increases and so the exchange rate must depreciate in order to clear goods markets.

From (64) it is clear that $\Delta \widehat{K} > 0$ when capital is below steady state and $\Delta \widehat{K} < 0$ otherwise.

For a sufficiently small value of δ , $\Omega_A > 0$ and $\Omega_K < 0$. And so from (65) it is clear that $\Delta \widehat{E} > 0$ when capital is below steady state and $\Delta \widehat{E} < 0$ otherwise.

This means that for a sufficiently small value of δ , the system is saddle-path stable. So, we have condensed the model to a system with one jump variable ($\widehat{E}$), one predetermined variable ($\widehat{K}$), and exactly one unstable root. This is qualitatively identical

Figure 8: Diagrammatic illustration of the system



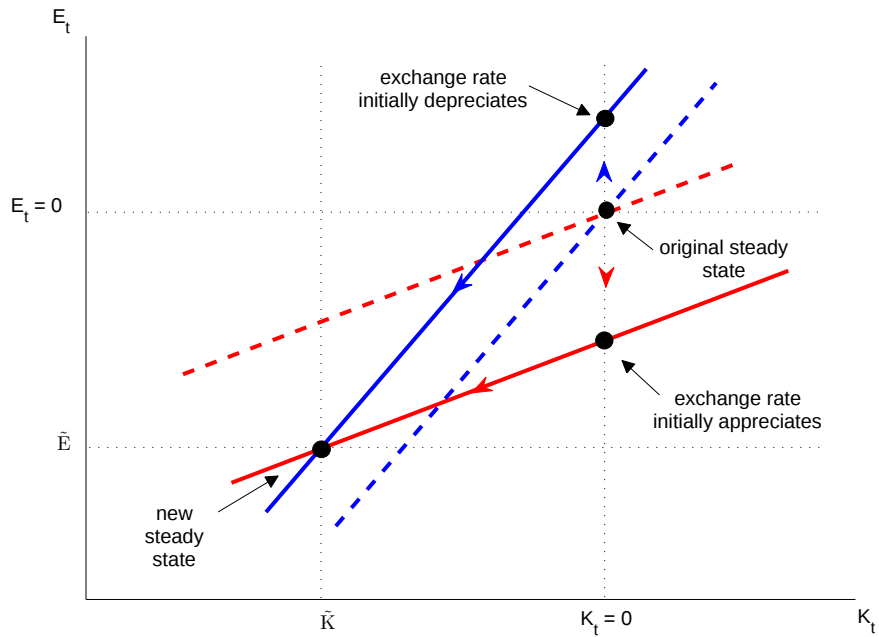
to the previous system (illustrated diagrammatically in section 2.6) that is also stable under the Blanchard-Kahn criterion.

When the permanent shock occurs, because this is a perfect foresight rational expectations equilibrium, the equilibrium schedule immediately shifts to pass through the new steady state $(\tilde{K}, \tilde{E})$. The new steady state is invariant to changes in the equilibrium dynamics of the model since it is pinned down by the exogenous shock to productivity.

Consider figure 9, the schedule can either shift up or down to pass through this new steady state. If $\mathbf{i}_2$ is sufficiently negative (or $\mathbf{c}_1$ is sufficiently positive), then the schedule is so steep (the blue lines) that the schedule needs to shift up in order to pass through the new steady state. In this case, the exchange rate initially depreciates before appreciating to its new long-run level.

If $\mathbf{i}_2$ is insufficiently negative (or $\mathbf{c}_1$ is insufficiently positive), the schedule is shallower (the red lines) and so it needs to shift down in order to pass through the new steady

Figure 9: Response to a productivity shock



state. In this case, the exchange rate initially appreciates and then continues gradually appreciating to the new long-run level. This ambiguity about whether the schedule shifts up or down in response to the shock is reflected by the ambiguous sign on the coefficient on $\hat{A}$ in equation (63).

The intuition for this is the same as for section 2.5. The steeper the schedule is, the more the exchange rate has to appreciate on a per-period basis for any given decumulation of capital. This may reflect imperfect capital mobility or some *ex ante* bias against holding home assets (which means that the exchange rate must appreciate by more on a per-period basis in order to compensate holders of home assets for the slow decumulation of capital). A larger cumulative per-period appreciation along the adjustment path then indicates a larger initial depreciation. This demonstrates the calibration-dependent nature of the initial jump of the exchange rate. Depending on the values of the parameters (represented here by the slope of the equilibrium schedule), the initial

jump can either be a depreciation or an appreciation (or there could be no jump at all).

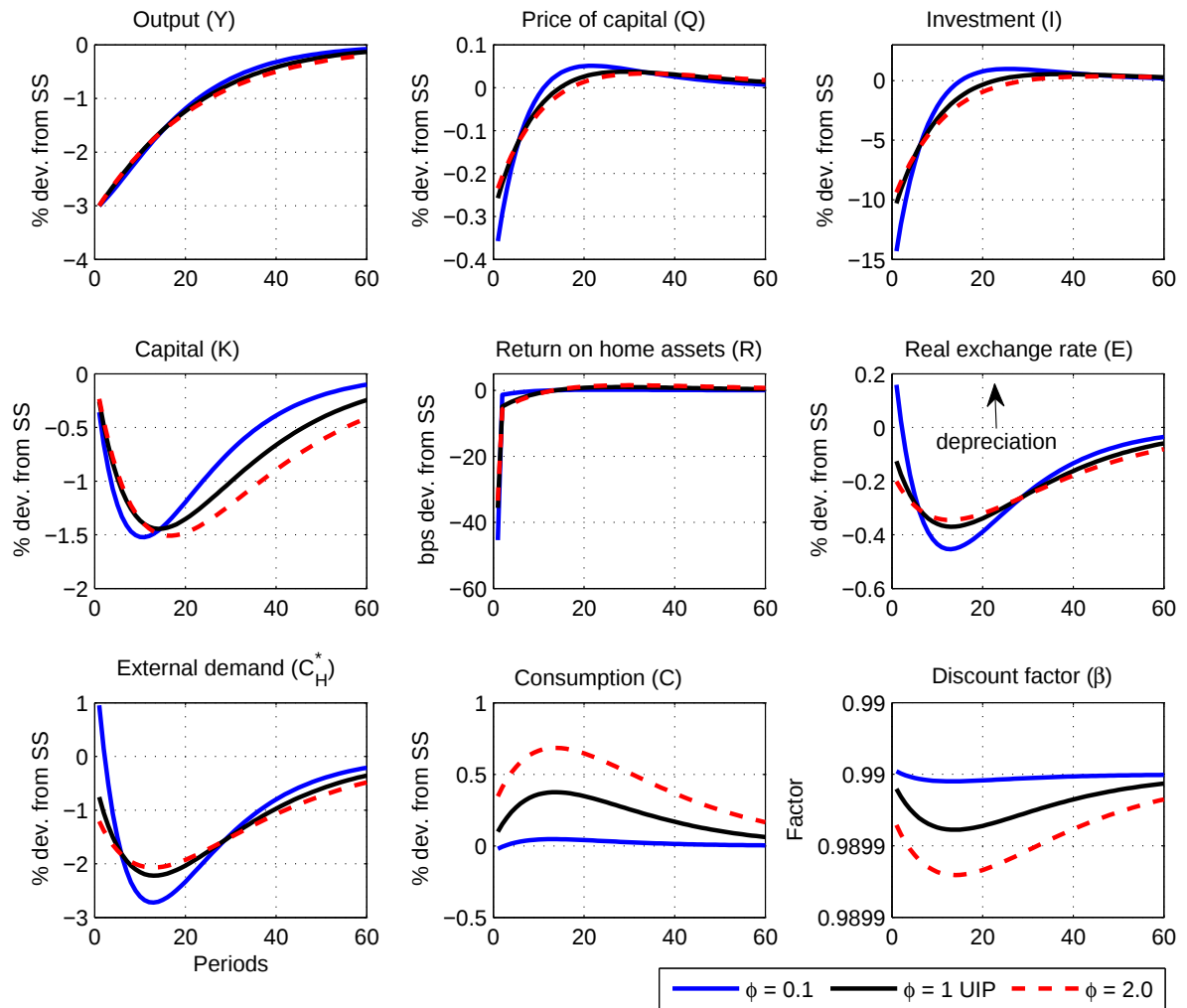
In summary, adding microfoundations to the simple model from section 2 leaves the implications of the stylised framework qualitatively unchanged. It remains appropriate to consider the long run level and the short run rate of change when accounting for the overall path of the exchange rate.

4 Simulation of a temporary shock

We simulate a temporary 3% fall in productivity. Following Peersman and Straub (2004) we impose an AR(1) structure on $\hat{A}$ with an autoregressive coefficient of 0.93. The results are shown in figure 10. Output falls initially in response to the shock but recovers. Even though capital decumulates, output recovers because the upward effect of the shock washing out dominates. The price of capital falls initially because capital becomes less productive and so demand for capital assets falls. The price of capital then rises because capital productivity recovers (both because capital decumulates and because the shock diminishes). Investment follows the path of Q and the capital stock thus decumulates before re-accumulating. Note that the home real interest rate R falls for only one period. It then shoots back up because the price of capital is always rising and this capital gain on holding home assets dominates the fall in the productivity of capital.

The exchange rate initially appreciates along the adjustment path (since the home real interest rate is below the world interest rate). When the home real interest rate rises above its original level (and hence is above the world rate), the exchange rate depreciates along the adjustment path. Hence we get a hump shaped path of the exchange rate with the change in direction occurring when the home real interest rate rises above the

Figure 10: Simulation of a temporary shock



world rate. This is what we would expect from the UIP condition. As ϕ decreases, the per-period adjustment required to ensure no arbitrage in asset markets and so the exchange rate initially jumps by more. This is qualitatively identical to the case of the permanent shock in section 4.2.

Chapter 2: Portfolio bias and exchange rate adjustment

Simon Wan ^{*†}

Abstract

We extend the analysis of Chapter 1 in order to examine the effect of imperfect asset substitutability (specifically, portfolio bias) on exchange rate adjustment. This Chapter presents three key results. First, we re-confirm the finding of an extensive theoretical literature that predicts home bias in asset allocations. Bias in asset allocations can arise (even when asset returns are equalised) because second-order characteristics of assets may differ and investors, all else equal, prefer assets that hedge against shocks to consumption. Under a reasonable parameterisation, our simple model predicts a plausible degree of home bias.

Second, the main result of this Chapter is that, in response to productivity shocks, portfolio bias increases the volatility of exchange rates, compared to the case of perfect substitutability. After a productivity shock, we show that the exchange rate initially overshoots its long-run level and thus exhibits higher volatility than in the case of perfect substitutability where it undershoots. The reason for this higher volatility is straightforward: if investors are biased, asset markets only clear when expected excess returns deviate sufficiently from zero in order to equilibrate supply and demand. Along the short-run path, the burden of adjustment on the exchange rate's per-period movement is thus greater than in the case of perfect substitutability (where expected excess returns do not deviate from zero).

The third key finding of this Chapter is that our main result (i.e. the second finding above) overturns that of a key paper on imperfect asset substitutability by Blanchard, Giavazzi and Sa (2005). This difference arises because Blanchard *et al.* treat the capital stock as fixed, while it is endogenised in our model.

JEL classification: F31, F32, G15

Keywords: portfolio bias, imperfect asset substitutability, exchange rate adjustment

^{*}Department of Economics, University of Oxford

[†]simon.wan@economics.ox.ac.uk

Contents

1	Introduction	86
1.1	Related literature	89
1.2	Structure of this Chapter	94
2	Microfoundations of portfolio bias	95
2.1	Model	95
2.2	Finding the optimal portfolio	102
2.3	Comparative statics	104
2.4	Implications of portfolio bias for exchange rate dynamics	110
3	Main Model	112
3.1	Production	112
3.2	Capital goods producers	114
3.3	Households	114
3.4	Consumption	116
3.5	Equilibrium conditions	117
3.6	Model summary	119
4	Simulations and model properties	122
4.1	Parameterisation	122
4.2	Baseline simulation – a negative productivity shock	123
4.3	More simulations – a temporary shock and a positive shock	132
4.4	Comparison with Blanchard, Giavazzi and Sa (2005)	135
4.5	Phase diagrams	144
5	Discussion	146
6	Concluding remarks	148

Appendix	154
1 Deriving the log-linearised model in Section 2	154
2 Deriving the steady state portfolio in Section 2	155
3 Deriving the log-linearised model in Section 3	157
4 Historical episodes of changes in national wealth	158
5 Extension — endogenous discount factor	161
6 Extension — the special case of foreign asset bias	165
7 Extension — a two-country model	169

1 Introduction

In this Chapter, we extend the analysis of Chapter 1 in order to examine the effect of imperfect asset substitutability on exchange rate dynamics. Specifically, we examine the effect of investor bias in allocating wealth between home and foreign assets. In doing so, we depart from the uncovered interest parity (UIP) condition, which depends on the assumption that assets in international markets are perfectly substitutable.

This Chapter presents three key results. First, this Chapter demonstrates how portfolio bias can arise, even when home and foreign assets yield the same return, if assets differ in their second-order characteristics. Specifically, investors prefer assets that provide insurance value against negative shocks to consumption. Under a reasonable parameterisation, domestic assets provide a better hedge against consumption shocks and so are favoured over foreign assets, all else equal. Hence this Chapter re-confirms the finding of an extensive theoretical literature (e.g. Baxter and Jermann, 1997; Palacios-Huerta, 2001; Coeurdacier, Kollmann and Martin, 2009; Engel and Matsumoto, 2009; Coeurdacier, Kollmann and Martin, 2010; Heathcote and Perri, 2013) that predicts home asset bias (a key stylised fact of international asset markets) but with an arguably more tractable model and very parsimonious assumptions.

Second, we find that, in response to productivity shocks, portfolio bias increases the volatility of the exchange rate compared to the case of perfect substitutability (UIP). Recall from Chapter 1 that, after a fall in productivity, the exchange rate under UIP appreciates along the adjustment path. Combined with a long-run appreciated level of the exchange rate, this implies initial undershooting and thus mild exchange rate volatility. Under home bias, a decline in productivity also causes a long-run appreciation. However, the exchange rate *depreciates* along the adjustment path in the short

run, which, combined with an appreciated long-run level, implies initial overshooting and thus greater volatility.

Thus the exchange rate, in response to a productivity shock, moves in the opposite direction to that predicted by UIP. The reason for this is straightforward. When aggregate productivity falls, home firms decumulate capital, causing the supply of the home asset to shrink. Because investors are biased, this fall in the supply of the home asset gives rise to excess demand for it even though its return has fallen. Hence, in order to clear this excess demand, the exchange rate must depreciate along the adjustment path in order to make the excess return on the home asset *sufficiently negative* that even biased investors wish to stop accumulating it. What is happening is that investors crowd into the now-relatively-scarcer home asset, causing financial inflows and an initial overshooting appreciation of the exchange rate until it is sufficiently over-valued relative to its long-run level. This is the point where the subsequent per-period depreciation of the exchange rate lowers the excess return on the home asset enough to dissuade even biased investors from holding more of it. Financial inflows stop and the exchange rate then gradually depreciates to its new long-run level.

This exchange rate movement after a negative productivity shock can be equivalently interpreted as a simple consequence of the asset equilibrium conditions of this model. Because of home asset bias, in steady state investors wish to hold a fixed fraction of their wealth that is higher than 50% in domestic assets. Because there are now fewer outstanding home assets than there were previously, in equilibrium it must be the case that home wealth declines at the new steady state. Put differently, world asset demand has to be redirected towards the foreign asset, which, because of the specified portfolio biases, would imply that foreign investors become wealthier relative to home investors. The over-valuation of the exchange rate along the adjustment path (caused

by its initial overshooting) achieves this required change in wealth by causing a current account deficit, which transfers wealth away from the home country.

So, we can interpret the greater volatility of the exchange rate under home bias (in response to productivity shocks) in one of two ways. First, it is a result of the fact that, when assets are imperfectly substitutable, the excess returns on assets have to be sufficiently positive or negative before investors are satisfied with their holdings. Hence the exchange rate has to do more “heavy lifting” in order to equilibrate asset markets when compared with the case of UIP, where expected excess returns are always zero in equilibrium because assets are treated as perfect substitutes *ex ante*. Second, this greater volatility is also the result of the fact that, under home bias, wealth stocks need to adjust following shocks. These movements in wealth are brought about by the exchange rate remaining under- or over-valued (relative to its long-run level) along the adjustment path. Hence under portfolio bias, there is an additional burden of adjustment on the exchange rate and so its volatility is augmented.

The third finding of this Chapter is that our main result (i.e. the second finding above) overturns a key paper on the effect of imperfect substitutability on exchange rates by Blanchard, Giavazzi and Sa (2005). The difference arises because Blanchard *et al.* treat the capital stock and the price of capital as fixed. Because of this, the implications for home and foreign wealth stocks are the opposite to that of our model. Suppose there is the same negative productivity shock as considered above. The exchange rate appreciates at the new steady state because the supply of home goods has declined. With a fixed capital stock, an appreciation of the exchange rate causes the value of outstanding home assets to *increase* at the new steady state. In the presence of home bias, this implies that home wealth needs to *rise*. Thus the exchange rate must be *under*-valued (relative to its long-run level) along the adjustment path (in order to induce a current

account *surplus*), implying that the exchange rate gradually appreciates to its long-run level. Hence, under Blanchard *et al.*'s model, imperfect asset substitutability implies slow and gradual exchange rate adjustment, as opposed to the overshooting predicted by a model with a moving capital stock like ours.

1.1 Related literature

We begin with a brief description of why imperfect asset substitutability became a feature of open macroeconomic models before outlining the related literature in more detail below.

It is fairly common in open economy macroeconomics to assume the existence of the uncovered interest parity condition. The asset equilibrium condition in Chapter 1 represented this assumption. Claus (2007 and 2011), Gertler, Gilchrist and Natalucci (2007), and Ueda (2012) are recent examples of models in the literature that have employed this assumption. The issue with assuming the existence of UIP, of course, is that the condition has repeatedly failed to be observed empirically. Most famously, Froot and Thaler (1990) found that UIP was not observed in over eighty studies, at least not at short time horizons.

A key problem with the UIP condition is that assets in international markets do not appear to be perfect substitutes. If this is the case, then, even in the absence of transaction costs, arbitrage will not drive the expected common currency returns of home and foreign assets to parity. Home and foreign assets do appear to be imperfect substitutes and this is demonstrated by the existence of bias in portfolio allocations. A substantial body of work (French and Poterba, 1991; Tesar and Werner, 1995; Warnock, 2002) has confirmed the fact that investors tend to allocate the majority of their wealth

at home (one of the puzzles documented in Obstfeld and Rogoff [2001]), although this bias is less apparent for emerging economies, and has been dampened as financial markets have become more globalised (Mercado Jr., 2013).

The relaxation of the assumption of perfect substitutability across home and foreign assets has led to the development of portfolio balance models (e.g. Branson and Henderson, 1985; Brainard and Tobin, 1992), in which the exchange rate is still determined in asset market equilibrium conditions but asset market arbitrage no longer implies that expected returns on assets are equalised. Likewise, in the models developed in this Chapter, it is no longer necessarily true that (common currency) home and foreign returns are driven to parity in equilibrium. So, the UIP condition is replaced by a set of equations that determine (in general equilibrium) the rate of change of the exchange rate necessary to keep investors satisfied with their asset holdings, given their biases in portfolio allocations.

(i) Home bias in portfolio allocation

The first part of this Chapter solves for the optimal portfolio of a representative household and predicts a plausible degree of home bias in asset allocations. This part of the Chapter is closely related to two strands of literature.

The first strand is the extensive work done on solving for optimal portfolios in international markets. The method we use is adopted from Devereux and Sutherland (2011), who develop a technique for finding the optimal asset holdings in steady state. If asset returns are equal in steady state, then, up to a first-order approximation, assets are identical and so asset holdings are indeterminate. Assets, however, may differ in terms of their second-order characteristics (covariance and variance) in that they offer greater

or lesser insurance value against negative consumption shocks. Devereux and Sutherland exploit these second-order differences in order to derive the optimal portfolio allocation.

Similar techniques have been devised to solve the same problem. Coeurdacier, Rey and Winant (2011) find the optimal asset holdings by finding the risky steady state. The stochastic, or risky, steady state, as opposed to the non-stochastic or deterministic steady state, takes into account the risk preferences of agents. It is defined as the point where agents would wish to remain if they expect future risk but the current realisation of shocks is zero. In this risky steady state, precautionary savings will typically cause investment to be higher and the interest rate to be lower. De Groot (2012) employs a similar method that involves solving for the second-order state space solution of the model using the technique of Schmitt-Grohe and Uribe (2004). Juillard (2011) demonstrates that all these methods are equivalent for the purposes of the problem we examine.

Applications of these techniques have emerged more recently. He and Luk (2013) use the method of Devereux and Sutherland in order to examine the effect of capital account liberalisation on portfolio holdings in China. The authors find that international risk-sharing improves with the removal of capital controls. The authors, however, do not study out-of-steady-state dynamics or characterise exchange rate behaviour.

The second strand of literature related to this first part of the Chapter is of course the theoretical work done on examining why home bias arises. One key objective of this literature is to find reasons as to why the return on home assets may be negatively correlated with non-diversifiable labour wages, hence explaining why home assets may be a good hedge against consumption shocks. As Baxter and Jermann (1997) showed, in a standard neoclassical model, this correlation is positive, which would imply foreign

asset bias, contrary to the data. Subsequent work (Palacios-Huerta, 2001; Coeurdacier, Kollmann and Martin, 2009 and 2010; Heathcote and Perri, 2013) has extended the basic open RBC model with features such as redistributive shocks (shifting shares of income between capital and labour) and investment efficiency shocks (driving a wedge between returns to capital and labour) in order to create a negative correlation instead. Other work has taken a different approach: Engel and Matsumoto (2009) find that, with sufficient price stickiness and an ability to hold forward foreign exchange positions, none of the burden of risk-sharing falls on equity assets, and hence optimal equity portfolios can remain highly biased and undiversified.

In the first part of this Chapter, all we do is use the methodology of the first strand of literature in order to re-confirm the prediction of home bias theoretically (the second strand of literature). Arguably our model is far simpler and more tractable than the models in the existing literature. In our model, home assets provide a better hedge against consumption shocks because of high levels of home bias in goods consumption, which is consistent with the empirical finding of Collard, Dellas, Diba and Stockman (2009) that high home asset bias is correlated with low goods import shares.

(ii) The effect of portfolio bias on exchange rate dynamics

The second and main part of this Chapter examines the effect of home asset bias on exchange rate adjustment.

The main insight this part of this Chapter relies on is from Blanchard, Giavazzi and Sa (2005). The authors consider the exchange rate adjustment required to correct the US current account deficit. In their model, investors exhibit home bias and wish to hold the majority of their wealth in domestic assets. A negative demand shock causes the

US to run a current account deficit. In order to restore trade balance, the exchange rate depreciates. However, as the value of the US dollar falls, the total value of US assets in the world falls. In asset market equilibrium, then, since the supply of US assets falls, world demand for assets must be redirected towards non-US assets. Because of the stipulated home asset biases, this means that US wealth must fall and non-US wealth must rise. This is achieved by a persistent US current account deficit that is only narrowed slowly. This implies that the exchange rate must experience a gradual slide to its new long-run value, so as to remain over-valued during the adjustment period. Kuralbayeva and Vines (2009) update Blanchard *et al.* by adding forward-looking consumers and find that the results are qualitatively similar. Krugman (2007) uses a reduced form version of the analysis of Blanchard *et al.* in order to argue for a possible large fall in the US dollar due to the deficit. This is because investors realise that the slow slide of the dollar predicted by Blanchard *et al.* is insufficient to correct the deficit, leading them to hold the self-fulfilling expectation of a plunge in the exchange rate.

The papers cited above use fairly strong assumptions and simple modelling features (for instance the interest rate is held as constant). More recent work has updated these models. For instance, Meredith (2007), Ghironi, Lee and Rebucci (2009), and Sa and Viani (2013) extend the model in Blanchard *et al.* to a fully-specified DSGE model. These papers, however, examine different issues from the one of interest in this Chapter. Sa and Viani (2013) and Meredith (2007) examine the effect on portfolio allocations of changes in preferences for home goods and assets. Ghironi *et al.* (2009) decompose the changes in the current account with the aim of identifying the importance of valuation effects. These authors do not explain how home bias affects exchange rates. For instance, Sa and Viani (2013) explain real exchange rate movements in their simulations in terms of changes to goods demand and without reference to the effect of home asset bias, which is the key rigidity in their model.

We make two contributions to this literature. First, we bridge the gap between (i) the methodology of the more recent portfolio balance models (e.g. Meredith, 2007) and (ii) the aims of Blanchard *et al.* and Kuralbayeva and Vines (2009). Hence, unlike Blanchard *et al.* we nest the discussion of imperfect asset substitutability in a full general equilibrium model in which production, the real interest rate, and capital are fully specified. In Blanchard *et al.*, interest rates are assumed to be constant and the analysis takes place within a partial model. Consumption is specified in an *ad hoc* manner. Fiscal policy is assumed to ensure that aggregate demand is fixed. In this Chapter, these simplifying assumptions are removed and replaced with a general equilibrium model. But unlike the more recent literature (e.g. Sa and Viani, 2013), we provide an explicit treatment of the effect of portfolio bias on exchange rate adjustment. Consistent with the focus of this thesis, we specifically examine how these real rigidities affect the exchange rate.

Second, this existing literature (Blanchard *et al.*; Kuralbayeva and Vines, 2009) argues that imperfect asset substitutability implies “slow slides” in exchange rates rather than rapid overshooting. In this Chapter, we show that imperfect asset substitutability, when combined with the slow adjustment process of capital accumulation, can augment the burden of adjustment on the exchange rate so much that it causes exchange rates to overshoot their long-run levels following shocks. Hence we show that adding our fundamental real rigidity (i.e. slow capital adjustment) to home asset bias can overturn the result in Blanchard *et al.*.

1.2 Structure of this Chapter

The remainder of this Chapter is structured as follows. Section 2 shows how portfolio bias can arise and predicts a plausible degree of home bias under a reasonable paramet-

erisation. Section 3 develops a portfolio balance model in order to explicitly investigate the effect of this portfolio bias on the exchange rate. Sections 4 and 5 present and summarise the results from simulations. Section 6 concludes.

2 Microfoundations of portfolio bias

The main model of this Chapter (in section 3) introduces an assumption of portfolio bias. In this section, we motivate this assumption of home asset bias in a microfounded manner. Using the solution method of Devereux and Sutherland (2011), we derive the optimal steady state portfolio of households from their optimal consumption behaviour. We first lay out a parsimonious model. We then derive the optimal steady state portfolio balance, which predicts a sensible degree of home asset bias.

2.1 Model

This is a model of a small open economy in which the home household has access to a home asset and a foreign asset. The home asset represents a real bond in home firms whose return is related to the productivity of home capital goods in general equilibrium. The foreign asset, which is in zero net supply, is a financial security that pays the same return as the home asset in steady state. Home and foreign goods are imperfect substitutes.

The purpose of this exercise is to find the optimal portfolio balance in steady state and thus demonstrate bias in portfolio allocation.

Production

The production side of this economy is closest to that in Luk and Vines (2011). The main difference is that we abstract from labour supply movements. The production function of the home good Y is given by

$$Y_t = A_t K_t^\alpha \quad (1)$$

where $\alpha \in (0, 1)$, K is the stock of capital goods at home, and A is an exogenous technology shock. We assume that the supply of labour from the representative household is normalised at one.

Capital goods producers build capital one period in advance and so the firms must make their production decision one period in advance as well. At the end of period t , firms decide how much capital to purchase for use in production in $t + 1$. After production has occurred, firms sell back undepreciated capital to the capital goods producer. We fix the price of capital at one. This is an assumption that simplifies the portfolio choice problem. In section 3, we introduce a varying price of capital Q . Firms fund this purchase of capital goods by issuing real bonds that pay a return R_{t+1} after production has occurred. This gives rise to the home asset.

This implies that firms solve the optimisation problem

$$\max_{K_{t+1}} \{ \mathcal{E}_t (Y_{t+1} + (1 - \delta) K_{t+1} - R_{t+1} K_{t+1}) \} \text{ subject to (1)}$$

This yields a first order condition

$$\mathcal{E}_t (R_{t+1}) = \mathcal{E}_t \left((1 - \delta) + \alpha \frac{Y_{t+1}}{K_{t+1}} \right)$$

which implies that the realised return on capital is an increasing function of the marginal product of capital

$$R_t = (1 - \delta) + \alpha \frac{Y_t}{K_t} \quad (2)$$

Capital goods producers build capital goods by combining undepreciated capital with an investment of I consumption goods. This implies that K evolves according to (where δ is the rate of depreciation)

$$K_{t+1} = (1 - \delta) K_t + I_t \quad (3)$$

Households

The consumption side of this economy is standard (e.g. CES goods aggregation, intertemporal optimisation) and most closely follows the formulation in He and Luk (2013) and Kuralbayeva and Vines (2009).

We construct the household's budget constraint. After production has occurred in period t , the household receives a wage income equal to the labour share of income $(1 - \alpha)Y_t$. The household also receives income from holding home and foreign assets obtained in the previous period, $H_{t-1}^H R_t + H_{t-1}^F R_t^* \frac{E_t}{E_{t-1}}$, where H_H and H_F are holdings of home and foreign assets, respectively, each denominated in terms of home goods. R^* is the exogenous return on the foreign asset. Home and foreign assets yield the same return in steady state. E is the real exchange rate defined as the price of foreign goods in terms of home goods. A rise in E denotes a depreciation for home. On the expenditure side, the household decides total aggregate consumption this period C , and asset holdings for next period H_t^H and H_t^F . Together, this implies that the budget

constraint is then given by

$$C_t + H_t^H + H_t^F = (1 - \alpha) Y_t + H_{t-1}^H R_t + H_{t-1}^F R_t^* \frac{E_t}{E_{t-1}} \quad (4)$$

We assume that the household exhibits log-utility. Its optimisation problem is (for discount factor $\beta \in (0, 1)$)

$$\max_{C_t, H_t^H, H_t^F} U_t = \sum_{i=t}^{\infty} \beta^{i-t} (\log C_i) \text{ subject to (4)}$$

This yields familiar Euler equations

$$\mathcal{E}_t \left(\frac{C_t}{C_{t+1}} R_{t+1} \right) \beta = 1 \quad (5)$$

$$\mathcal{E}_t \left(\frac{C_t}{C_{t+1}} R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \beta = 1 \quad (6)$$

Consumption

The Euler equation determines the path of aggregate consumption. Within each period, the household decides how to split consumption between home- and foreign-produced goods. We assume that aggregate consumption is given by a constant elasticity of substitution index (Gali and Monacelli, 2005)

$$C_t = \left[\gamma^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1 - \gamma)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (7)$$

where C_H and C_F are, respectively, the demands for home- and foreign-produced goods. $\gamma \in (0, 1)$ represents the degree of home bias in consumption. η is the price elasticity of substitution between home and foreign goods. Furthermore, we assume a similar form

for the aggregate price index

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1-\gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (8)$$

where the household faces a price P_H for home goods and P_F for foreign goods.

Given these functional forms for C and P , it is straightforward to show that the household's demands for home- and foreign-produced goods are, respectively

$$C_{Ht} = \gamma C_t \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (9)$$

$$C_{Ft} = (1-\gamma) C_t \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} \quad (10)$$

We take the home good as the numeraire (Sa and Viani, 2013) and we assume that the law of one price holds (Gali and Monacelli, 2005)

$$P_{Ht} = 1 \quad (11)$$

$$P_{Ft} = E_t \quad (12)$$

Finally, following Gertler, Gilchrist and Natalucci (2007), we assume that foreign demand for home goods is given by a function that is increasing in the depreciation of the exchange rate

$$C_{Ht}^* = (1-\gamma) \bar{C} E_t^\mu \quad (13)$$

Equilibrium conditions

The equilibrium condition for home goods is given by equating supply of home goods with demand for home goods

$$Y_t = C_{Ht} + C_{Ht}^* + I_t \quad (14)$$

We define home financial wealth W as home holdings of assets. It follows from the budget constraint (4)

$$W_{t+1} \equiv H_t^H + H_t^F \quad (15)$$

$$= -C_t + (1 - \alpha) Y_t + H_{t-1}^H R_t + H_{t-1}^F R_t^* \frac{E_t}{E_{t-1}} \quad (16)$$

Following Blanchard *et al.* and Kuralbayeva and Vines (2009), the equilibrium conditions for home and foreign assets are given by equating demand for and supply of these assets. Recall that the foreign asset is in zero net supply

$$K_{t+1} = H_t^H + H_t^{*H} \quad (17)$$

$$0 = H_t^F + H_t^{*F} \quad (18)$$

where H^{*H} and H^{*F} are, respectively, foreign holdings of home and foreign assets.

Combining (17) and (18) and using the definition of country wealth (15) gives the combined asset equilibrium condition

$$K_{t+1} = W_{t+1} + W^* \quad (19)$$

where foreign wealth W^* is taken as constant.

Model summary

The non-linear model consists of the equations (1)-(3), (5)-(6), (8)-(14), (16), and (19). This model is rank deficient in that there are two more endogenous variables than there are independent equations. This is a common problem with portfolio choice models. In order to solve the problem of rank deficiency, we use the method of Devereux and Sutherland (2011). This involves two preliminary steps.

First, we use the definition of total home wealth $H_{t-1}^F \equiv W_t - H_{t-1}^H$ in order to eliminate H^F . Second, we log-linearise the entire model¹. Log-linearising the model is useful because, in the linear approximation, the first-order variation of portfolio holdings, $\widehat{H}^H$, disappears since, in log-linearising the budget constraint, we get the term $\widehat{H}^H \overline{H}^H (\overline{R} - \overline{R}^* \frac{\overline{E}}{\overline{E}}) = 0$ (since $\overline{R} = \overline{R}^*$). We now have as many equations as variables.

This condenses the model into the following system (see Appendix 1 for derivations)

$$0 = \mathcal{E}_t (\widehat{C}_t - \widehat{C}_{t+1} + \widehat{R}_{t+1}) \quad (20)$$

$$0 = \mathcal{E}_t (\widehat{C}_t - \widehat{C}_{t+1} + \widehat{R}_{t+1}^* + \widehat{E}_{t+1} - \widehat{E}_t) \quad (21)$$

$$\widehat{Y}_t = \widehat{A}_t + \alpha \widehat{K}_t \quad (22)$$

$$\widehat{R}_t = \left(1 - \frac{1-\delta}{\overline{R}}\right) (\widehat{Y}_t - \widehat{K}_t) \quad (23)$$

$$\widehat{K}_{t+1} = (1-\delta) \widehat{K}_t + \delta \widehat{I}_t \quad (24)$$

$$\overline{Y} \widehat{Y}_t = \gamma \overline{C} \widehat{C}_t + (1-\gamma) \overline{C} (\gamma \eta + \mu) \widehat{E}_t + \overline{I} \widehat{I}_t \quad (25)$$

$$\widehat{K}_{t+1} = \widehat{W}_{t+1} \quad (26)$$

$$\begin{aligned} \widehat{W}_{t+1} = & -\frac{\overline{C}}{\overline{W}} \widehat{C}_t + (1-\alpha) \frac{\overline{Y}}{\overline{W}} \widehat{Y}_t + \frac{\overline{H}^H \overline{R}}{\overline{W}} \widehat{R}_{Xt} \\ & + \overline{R} (\widehat{W}_t + \widehat{R}_t + \widehat{E}_t - \widehat{E}_{t-1}) \end{aligned} \quad (27)$$

¹ $\overline{x}$ denotes the steady state level and $\widehat{x}$ denotes the log-deviation from that steady state $\widehat{x} \approx \log(\frac{x}{\overline{x}})$.

where $\widehat{R}_X \equiv \widehat{R} - \widehat{R}^* - (\widehat{E}_t - \widehat{E}_{t-1})$ is the excess return on home assets. These equations determine the equilibrium dynamics for the variables

$$\{\widehat{C}_t, \widehat{Y}_t, \widehat{R}_t, \widehat{K}_t, \widehat{I}_t, \widehat{E}_t, \widehat{W}_t\}_{t=1}^{\infty}$$

given the exogenous processes for $\widehat{A}$ and $\widehat{R}^{*2}$

$$\widehat{A} \sim \text{iid}(0, \sigma^2)$$

$$\widehat{R}^* \sim \text{iid}(0, \sigma^{*2})$$

The task now in the rest of this section is to find the steady state holdings of the home asset $\overline{H^H}$ using the approach adopted from Devereux and Sutherland (2011). We will show that, under a reasonable parameterisation, the steady state proportion of home wealth allocated to the home asset ($\frac{\overline{H^H}}{\overline{W}}$) is greater than 50%, which replicates the observation of home bias in asset allocations.

2.2 Finding the optimal portfolio

We complete the development of the model by finding the steady state value of portfolio holdings at home $\overline{H^H}$. The method of Devereux and Sutherland involves two steps. The first step is to find the equation that determines portfolio balance for the household. The conditions describing household behaviour are the Euler equations

$$\mathcal{E}_t \left(\frac{C_t}{C_{t+1}} R_{t+1} \right) \beta = 1 \quad (28)$$

$$\mathcal{E}_t \left(\frac{C_t}{C_{t+1}} R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \beta = 1 \quad (29)$$

²Following Devereux and Sutherland (2010 and 2011), we assume no persistence in these stochastic processes.

By taking second-order approximations³ of (28) and (29) and combining these approximations, we get the following equation which determines portfolio balance

$$\mathcal{E}_t(\widehat{R}_{X_{t+1}}) = \mathcal{E}_t(\widehat{R}_{X_{t+1}}\widehat{C}_{t+1}) \quad (30)$$

The second step of finding the steady state portfolio balance is to find the state space solution of the log-linearised model and then to substitute the relevant terms into the arbitrage condition (30) (see Appendix 2 for details). This yields a restriction on $\frac{\overline{H^H}}{W}$ - the proportion of the home portfolio held in the home asset - as a function of $\frac{\sigma}{\sigma^*}$, the standard deviation of the home productivity shock relative to the standard deviation of the foreign asset return.

To understand what determines the steady state portfolio balance $\frac{\overline{H^H}}{W}$, consider the portfolio arbitrage condition, equation (30)

$$\begin{aligned} \mathcal{E}_t(\widehat{R}_{X_{t+1}}) &= \mathcal{E}_t(\widehat{R}_{X_{t+1}}\widehat{C}_{t+1}) \\ &= \text{Cov}(\widehat{R}_{X_{t+1}}, \widehat{C}_{t+1}) \end{aligned}$$

Equation (30) essentially states that households prefer assets whose return is negatively correlated with consumption, since this implies that these assets insure against negative shocks to consumption. If $\text{Cov}(\widehat{R}_X, \widehat{C}) > 0$, home assets provide less hedging value against negative shocks to consumption (compared with foreign assets) and so, as

³The reason why we need a second-order approximation is straightforward. Taking a first-order approximation of equations (28) and (29) only yields $\mathcal{E}_t(\widehat{R}_{X_{t+1}}) = 0$ (i.e. the excess return on home assets is zero in expectation). With a first-order approximation, households exhibit certainty equivalence behaviour and so, given that returns are equal in steady state, the home and foreign assets are treated as perfect substitutes and portfolio holdings are indeterminate. But the assets differ in terms of risk characteristics (by providing different degrees of insurance value against negative shocks), and so are imperfect substitutes up to a second-order approximation. This means we can use a second-order restriction to pin down the differences in assets and hence the optimal portfolio.

equation (30) implies, they must earn a positive excess return in order for consumers to be indifferent between them and the foreign asset. We could interpret a positive excess return as the risk premium demanded of the asset that provides less insurance value. Asset markets are in equilibrium (i.e. investors are indifferent between the two assets) only when the asset that provides less hedging value earns a positive excess return that is equal in the magnitude to the covariance $|\text{Cov}(\widehat{R}_X, \widehat{C})|$.

Portfolio bias thus arises if one type of asset provides better insurance value than the other. Since both assets in steady state yield the same return, bias in the steady state portfolio can only arise due to differences in the second-order (or higher order) characteristics of these assets. Specifically, households prefer the asset whose return is more negatively correlated with future consumption.

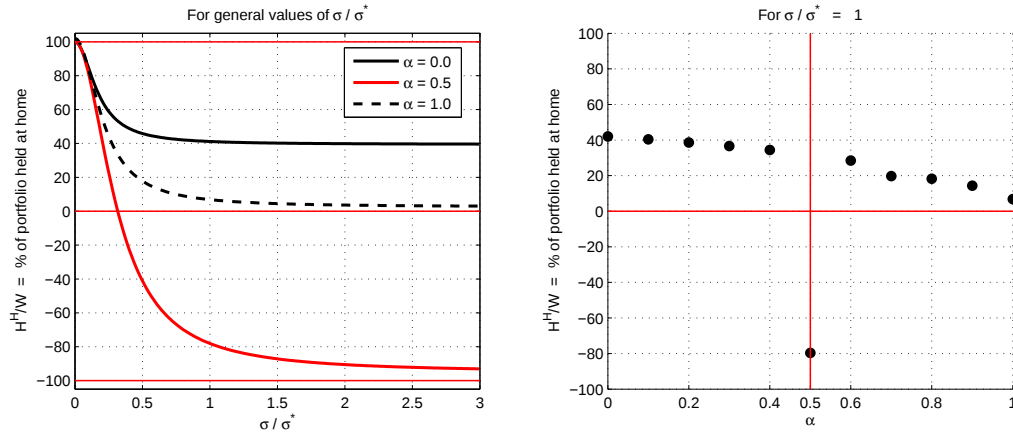
2.3 Comparative statics

In order to illustrate this driver of portfolio bias more concretely, consider, for example, one important factor affecting the household's optimal portfolio. Recall that the home household has a non-diversifiable source of labour income equal to $(1 - \alpha) Y_t \equiv (1 - \alpha) A_t K_t^\alpha$. Because this labour income and the return on the home asset are strongly correlated (because they are both affected by the home productivity shock), we would expect this to cause the household to diversify away from the home asset.

We plot the optimal steady state proportion of home wealth that is held in the home asset $\frac{H^H}{W}$ as a function of the relative standard deviations of shocks $\frac{\sigma}{\sigma^*}$. Unless otherwise noted, we use the numerical values for parameters shown in table 1. All values are within standard ranges in the literature. We discuss parameterisation more extensively in section 4.1.

Table 1: Parameters for computing steady state portfolio

Parameter	Value
Capital share of income α	0.35
Discount factor β	0.99
Depreciation rate δ	0.025
Home bias in goods consumption γ	0.85
Price elasticity of substitution in home/foreign goods η, μ	2.0

Figure 1: The effect of the capital share of income α on the steady state portfolio $\frac{H^H}{W}$ 

Consider figure 1. The left-hand panel plots $\frac{H^H}{W}$ as a function of $\frac{\sigma}{\sigma^*}$ for various values of the capital share of income α . When $\frac{\sigma}{\sigma^*} = 0$, the household wishes to hold all of its wealth in the home asset in steady state. When $\frac{\sigma}{\sigma^*} = 0$, the home asset is riskless and so the risk averse household would optimally hold all its wealth in this asset. This optimal holding then declines as $\frac{\sigma}{\sigma^*}$ increases. This is a simple consequence of risk-averse behaviour of the household.

When $\alpha = 0.5$, the return on the home asset is *perfectly* positively correlated with the household's non-diversifiable labour income (this is a simple consequence of the Cobb Douglas production function) and so, as we expect, the home household does not hold the home asset in steady state. In fact, the home household optimally holds a negative position (i.e. a short position) in the home asset. As α moves away from 0.5,

labour income and the home asset return are no longer perfectly correlated and so the household holds more of its wealth in the home asset. (The changes in the portfolio balance in the vicinity of $\alpha = 0.5$ are large because of the non-linearity in the second-order moments of the system. At $\alpha = 0.5$, the correlation between asset and labour income is perfect, but a small movement away from $\alpha = 0.5$ lowers the correlation substantially and so significantly affects the portfolio balance accordingly.)

We can also interpret the effect of other parameters on $\frac{\overline{H^H}}{\overline{W}}$ by considering their effects on the insurance value of the home asset. Consider figure 2. The top-left panel reproduces data from figure 1 and shows that as α moves towards 0.5, $\frac{\overline{H^H}}{\overline{W}}$ declines. This is because as α moves towards 0.5, the return on home assets becomes more correlated with labour income and so households optimally diversify away from the home asset in steady state.

The top-right panel of figure 2 shows that as home bias in goods consumption γ rises, $\frac{\overline{H^H}}{\overline{W}}$ also rises. As the preference for home goods rises, the household prefers to receive an asset income denominated in home goods rather than in foreign goods. So, as γ rises, the preference for home assets also rises. To illustrate: after a negative productivity shock, home labour income falls. The absolute return on home assets R also falls. However, the exchange rate appreciates $E \downarrow$ (because the supply of home goods falls), making home goods more expensive. Hence, as the preference for home goods rises, *ceteris paribus* the preference for home assets also rises because, after a fall in labour income, home assets (although their absolute rate of return R falls) retain their value in terms of the good that investors wish to consume (i.e. home goods) while foreign assets (although their rate of return has not changed) fall in value due to re-denomination.

The bottom-left panel shows that as the price elasticity of demand η falls, $\frac{\overline{H^H}}{\overline{W}}$ rises. As η declines, the change in the exchange rate after shocks is amplified. As goods demand becomes less price-elastic, larger changes in the relative price of goods are

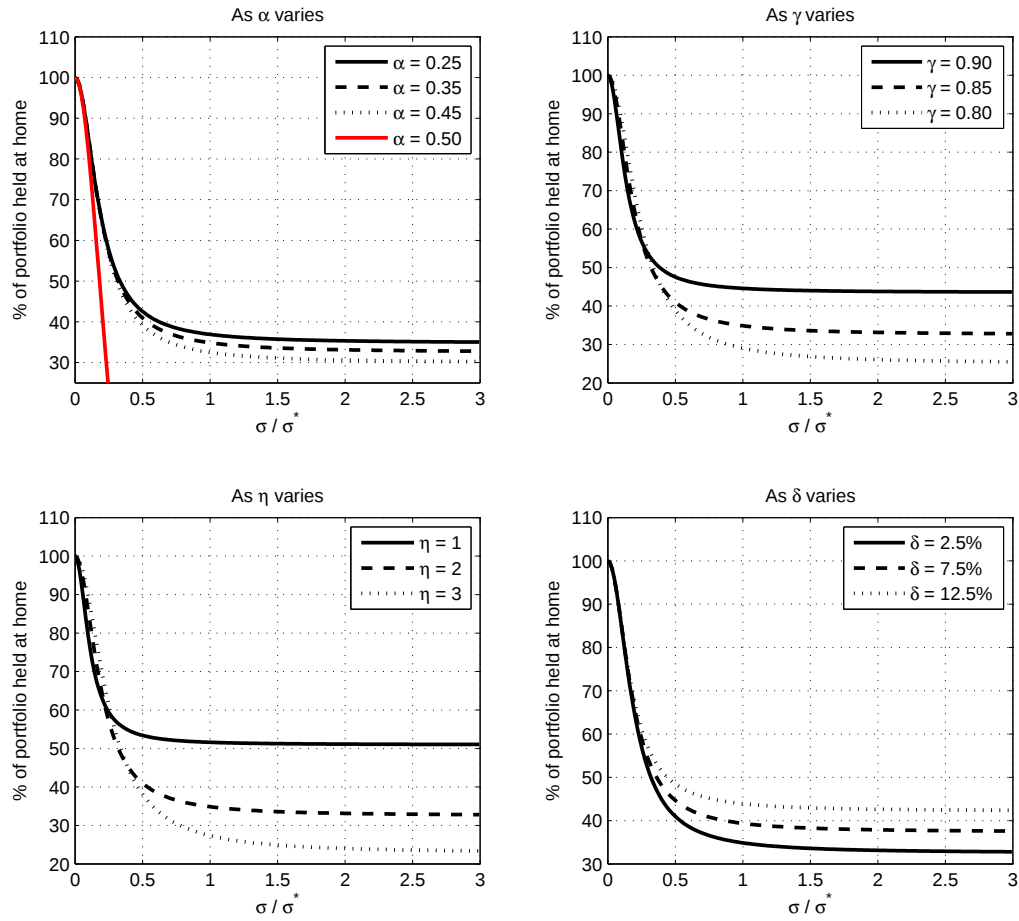
required to equilibrate goods markets. This in turn implies that the return on foreign assets becomes more volatile because the value of foreign goods relative to home goods fluctuates by more following shocks.

Finally, the bottom-right panel shows that as the rate of capital depreciation δ rises, $\frac{H^H}{W}$ rises. As δ rises, the consumption share of output falls because more investment is required in steady state. This in turn indicates that the consumption of home households becomes less correlated with the supply of home goods and the home productivity shock and so home assets provide greater hedging value against shocks.

Home bias in asset allocation

What the top-right and bottom-left panels of figure 2 suggest is that a reasonably low value of η and a high value of γ would lead to home bias in asset allocations. In figure 3 we consider the case where $\eta = 1.2, \gamma = 0.9$. These parameter values are within the standard ranges for advanced economies in Western Europe and North America (see our discussion of parameterisation in section 4.1).

In figure 3, we see that, under this parameterisation, the home household holds $\sim 64\%$ of its wealth in the home asset. That is, the household exhibits home asset bias. This arises due to reasons discussed above. Because the degree of home bias in consumption is high, consumption largely consists of home goods and so the household prefers to hold an asset whose return also consists of home goods, thus avoiding the re-denomination risk of holding foreign assets. Furthermore, lowering the value of η makes home assets even more relatively attractive because this increases the change in the exchange rate after a shock. Lowering η thus raises the volatility of the real return on foreign assets, making home assets more preferable. Hence, under this parameterisation, households prefer home assets, all else equal.

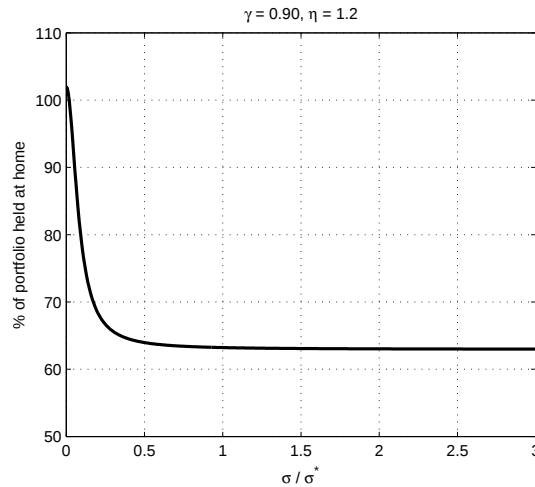
Figure 2: The effect of other parameters on the steady state portfolio $\frac{H^H}{W}$ 

To illustrate: consider a negative shock to home labour income caused by a fall in productivity. The absolute return on home assets falls because the marginal product of capital declines. However, the home exchange rate appreciates because the supply of home goods falls: the value of foreign assets falls relative to home goods. Hence if γ is sufficiently high (that is, if consumption is sufficiently dominated by home goods) then home investors would prefer home assets (over foreign assets) because, after a negative shock to labour income, these assets still yield a higher return in terms of the good households wish to consume (i.e. home goods) even though their absolute rate of return R has fallen. Similarly, as η declines, the home exchange rate appreciates by more after a negative shock to labour income, which, all else equal, makes foreign assets worth less in terms of the home good and thus makes the home asset more attractive to home investors.

The $\sim 64\%$ portfolio balance in figure 3 comes close to the $\sim 75\%$ home bias that is observed in the US. So, we re-confirm the finding of an extensive theoretical literature that predicts home asset bias (Baxter and Jermann, 1997; Engel and Matsumoto, 2009). As discussed in section 1.1, much of this work (Palacios-Huerta, 2001; Coeurdacier, Kollmann and Martin, 2009 and 2010; Heathcote and Perri, 2013) has focused on model features that ensure a negative covariance between consumption (or labour income) and the home asset return. Arguably, our model does this relatively simply by assuming a high degree of goods consumption bias, which is consistent with the argument for home asset bias in Heathcote and Perri (2013)⁴. This is also consistent with the empirical finding in Collard *et al.* that home asset bias is highly correlated with low goods import shares (and hence high home goods bias).

⁴Heathcote and Perri (2013) argue that volatile fluctuations in international relative prices (that is, the exchange rate) make domestic assets a better hedge (compared with foreign assets), especially when domestic consumption is dominated by home-produced goods (that is, when goods consumption bias is high).

Figure 3: Finding home bias in asset allocation



2.4 Implications of portfolio bias for exchange rate dynamics

We have demonstrated in a microfounded way that bias in portfolio allocations can arise from parsimonious model assumptions. If the second-order properties of assets differ, that is, if assets provide different degrees of insurance value against consumption shocks, then bias in asset allocations can arise. Specifically, with a sufficiently high degree of goods consumption bias, the risk averse household optimally holds the majority of its wealth in home assets. The main question we wish to address in this Chapter is how this portfolio bias affects exchange rate dynamics. Here we briefly preview the main result of the remaining part of this Chapter. Suppose that, because of portfolio bias, in steady state investors wish to hold a fixed fraction of their wealth that is greater than 50% in domestically-issued assets.

Consider a scenario in which the home country experiences a sustained negative productivity shock and so the home stock of capital decumulates. Hence the supply of home assets falls, while the supply of foreign assets remains unchanged. Because home investors wish to hold a fixed fraction (higher than 50%) of wealth in the home asset but there are now fewer home assets than previously, the equilibrium outcome must

be that home wealth declines at the new steady state. Interpreted in another way, in equilibrium, the world demand for assets must be directed towards foreign assets. And because of home bias, this would require that foreigners become wealthier relative to home residents. It is straightforward to show this algebraically⁵.

This change in wealth is brought about by the movement of the exchange rate. This decrease in home wealth implies that the exchange rate needs to initially over-appreciate beyond its (appreciated) long-run level before gradually depreciating along the adjustment path. This initial over-appreciation causes a current account deficit that lowers home net wealth. Furthermore, the gradual per-period depreciation in the subsequent periods gives rise to a negative valuation effect that reinforces the fall in home wealth caused by the current account deficit. The more home wealth needs to decrease in equilibrium, the greater the initial current account deficit and the subsequent valuation effects need to be, and so the larger the initial over-appreciation (overshooting) of the exchange rate.

⁵Suppose that, in a symmetric world with two countries, each country holds θ proportion of its wealth domestically and $1 - \theta$ abroad. Both countries exhibit home bias and so $1/2 < \theta \leq 1$. Then in the original steady state, equilibrium in asset markets implies

$$\begin{aligned}\bar{K} &= \theta W + (1 - \theta) W^* \\ \bar{K} &= (1 - \theta) W + \theta W^*\end{aligned}$$

with home and foreign wealth equal $W = W^* = \bar{K}$. Now suppose that the foreign asset supply remains unchanged at $\bar{K}$ while the home asset supply declines to $\phi \bar{K} < \bar{K}$ for $\phi \in (0, 1)$. Then asset equilibrium in the new steady state implies

$$\begin{aligned}\phi \bar{K} &= \theta \widetilde{W} + (1 - \theta) \widetilde{W}^* \\ \bar{K} &= (1 - \theta) \widetilde{W} + \theta \widetilde{W}^*\end{aligned}$$

which in turn implies that at the new steady state, home wealth $\widetilde{W}$ has decreased, while foreign wealth $\widetilde{W}^*$ has increased (for home bias, i.e. $\theta \in (\frac{1}{2}, 1]$)

$$\begin{aligned}\widetilde{W} &= \bar{K} \frac{\theta(1 + \phi) - 1}{2\theta - 1} < \bar{K} \\ \widetilde{W}^* &= \bar{K} \frac{\theta(1 + \phi) - \phi}{2\theta - 1} > \bar{K}\end{aligned}$$

The description above was a *reduced form* view of how wealth and the exchange rate adjust in this model. The intuitive *structural form* view is straightforward. Because the shock makes the home asset relatively scarcer, biased investors crowd into the home asset, causing financial inflows. This causes the exchange rate to appreciate and overshoot until the currency is so over-valued (relative to its long-run equilibrium level) that even biased investors no longer find the home asset attractive to continue accumulating. The movement in wealth follows from the movement in the exchange rate: the over-valuation of the exchange rate along the adjustment path lowers net national savings (lowering exports and raising imports *ceteris paribus*) and hence causes home net wealth to decline. The remainder of this Chapter formalises these results.

3 Main Model

Now that we have a microfounded basis for portfolio bias, we proceed to develop a model with this feature in order to examine its effect on exchange rate dynamics. Investors in the home country can invest in either the home capital stock or a foreign asset that yields the same return in steady state. We suppose that, in steady state, investors hold a fixed fraction of wealth greater than 50% domestically (i.e. they exhibit home bias). Many equations in this model are identical to those in section 2 (drawing from Kuralbayeva and Vines [2009] for the household and consumption side and Luk and Vines [2011] for the production side) but we present them again for completeness.

3.1 Production

The home country produces a good that is imperfectly substitutable with goods produced in the rest of the world. The home good is produced by home firms using a

simple Cobb-Douglas technology

$$Y_t = A_t K_t^\alpha \quad (31)$$

where A_t denotes the exogenously-given level of technology, $\alpha \in (0, 1)$, and K_t is the home stock of capital.

The timing of capital goods production is as follows. At the end of each period t , home firms sell any undepreciated capital goods from production in the current period $((1 - \delta) K_t)$ for the prevailing price of Q_t . At the same time, home firms purchase (at the same price Q_t) a stock of capital goods K_{t+1} for use in production in the next period. Firms pay for these capital goods by issuing assets to households that pay a return R_{t+1} after production has occurred next period.

This implies that in period t , home firms maximise the expected profits of production in the next period. That is, home firms solve

$$\max_{K_{t+1}} \{ \mathcal{E}_t (Y_{t+1} + (1 - \delta) Q_{t+1} K_{t+1} - R_{t+1} Q_t K_{t+1}) \} \text{ subject to (31)}$$

which yields a first-order condition defining the expected return on home capital

$$\mathcal{E}_t (R_{t+1} Q_t) = \mathcal{E}_t \left((1 - \delta) Q_{t+1} + \alpha \frac{Y_{t+1}}{K_{t+1}} \right) \quad (32)$$

The realised return on home capital is given by

$$R_t = \frac{1}{Q_{t-1}} \left((1 - \delta) Q_t + \alpha \frac{Y_t}{K_t} \right) \quad (33)$$

3.2 Capital goods producers

Capital goods producers build capital goods using an investment of consumption goods. The stock of capital evolves according to

$$K_{t+1} = (1 - \delta) K_t + I_t - \frac{\xi (K_{t+1} - K_t)^2}{2 K_t} \quad (34)$$

where $\delta \in (0, 1)$ is the rate of depreciation, ξ represents the cost of capital adjustment, and I_t is investment in terms of home goods.

At the end of each period t , home firms purchase stock K_{t+1} of capital goods for production in the next period. At the same time, capital goods producers buy back the undepreciated stock of capital from the current period at the prevailing price. They also purchase I_t units of home goods at price P_{Ht} and combine these with the undepreciated capital to build next period's capital stock.

This implies that capital goods producers solve

$$\max_{I_t} \{Q_t K_{t+1} - Q_t (1 - \delta) K_t - P_{Ht} I_t\} \text{ subject to (34)}$$

This yields a first-order condition that determines the current price of capital

$$Q_t = P_{Ht} \left(1 - \xi + \xi \frac{K_{t+1}}{K_t} \right) \quad (35)$$

3.3 Households

Consider the household budget constraint. After production has occurred in period t , the consumer receives a wage income equal to the labour share of income $(1 - \alpha)Y_t$.

The household also receives asset income. We denominate the financial wealth of the home country in terms of foreign goods⁶.

The home household allocates proportion θ_t of its wealth W_t at home and the rest abroad. Home bias in asset allocations implies that in steady state $\frac{1}{2} < \bar{\theta} \leq 1$. The asset demand function θ_t takes the same form as in Kuralbayeva and Vines (2009). The total demand for home assets by the home household is

$$\theta_t W_{t+1} = \bar{\theta} \mathcal{E}_t \left(\frac{R_{t+1}}{R_{t+1}^* \frac{E_{t+1}}{E_t}} \right)^\zeta W_{t+1} \quad (36)$$

where $\zeta > 0$ denotes the elasticity of substitution between assets. Hence demand for home assets (by the home household) is increasing in total wealth and in the expected excess return on home assets. This formulation of portfolio allocation also follows closely that of Meredith (2007) and Sa and Viani (2013)⁷.

Sa and Viani (2013) note that these simple forms for asset allocation functions allow for an easy parameterisation to match data without having to make assumptions on the determinants of these holdings. Likewise, in this part of this Chapter, having already examined the determinants of portfolio allocation and home bias in the previous sections, we choose an *ad hoc* specification in (36) to abstract away from these other considerations so as to focus on the question of exchange rate adjustment.

We define W in terms of foreign goods. So, after production has occurred in period t , the consumer receives a return of $\theta_{t-1} W_t R_t \frac{E_{t-1}}{E_t}$ from its holdings at home and a return $(1 - \theta_{t-1}) W_t R_t^*$ from its holdings in the foreign asset. R^* is the exogenous stochastic return on the foreign asset whose mean is equal to the steady state return on home

⁶This is done simply to harmonise the denomination of wealth and assets across international asset markets.

⁷In these two papers, the function we call θ_t is a linear function of the excess return and a constant.

assets. E is the real exchange rate defined as the price of foreign goods in terms of home goods. A rise in E denotes a depreciation for home.

On the expenditure side, the household decides how much to consume in aggregate ($\frac{C_t}{E_t}$) and how much to save for next period (W_{t+1}). The consumer's budget constraint is thus given by

$$\frac{C_t}{E_t} + W_{t+1} = (1 - \alpha) \frac{Y_t}{E_t} + \theta_{t-1} W_t R_t \frac{E_{t-1}}{E_t} + (1 - \theta_{t-1}) W_t R_t^* \quad (37)$$

Assuming log-utility, the household's optimisation problem is

$$\max_{C_t, H_t^H, H_t^F} U_t = \mathcal{E}_t \sum_{i=t}^{\infty} \beta^{i-t} (\log C_i) \text{ subject to (37)}$$

where $\beta \in (0, 1)$ is the discount factor. This yields an Euler equation

$$\mathcal{E}_t \left[\frac{C_t}{C_{t+1}} \left(\theta_t R_{t+1} + (1 - \theta_t) R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \right] \beta = 1 \quad (38)$$

3.4 Consumption

Within each period, the household decides how to split consumption between home- and foreign-produced goods. We assume aggregate consumption and price indices of the same form as in section 2

$$C_t = \left[\gamma^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1 - \gamma)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (39)$$

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1 - \gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (40)$$

which implies demand functions of the same form

$$C_{Ht} = \gamma C_t \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (41)$$

$$C_{Ft} = (1 - \gamma) C_t \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} \quad (42)$$

Again, we take the home good as the numeraire (Sa and Viani, 2013) and we assume that the law of one price holds (Gali and Monacelli, 2005)

$$P_{Ht} = 1 \quad (43)$$

$$P_{Ft} = E_t \quad (44)$$

Foreign demand for home goods is given by (Gertler, Gilchrist and Natalucci, 2007)

$$C_{Ht}^* = (1 - \gamma) \bar{C} E_t^\mu \quad (45)$$

The evolution of home financial wealth implied by the budget constraint (37) is

$$W_{t+1} = (1 - \alpha) \frac{Y_t}{E_t} - \frac{C_t}{E_t} + W_t \left(\theta_{t-1} R_t \frac{E_{t-1}}{E_t} + (1 - \theta_{t-1}) R_t^* \right) \quad (46)$$

3.5 Equilibrium conditions

Equilibrium in the goods market equalises the supply of and demand for home goods

$$Y_t = C_{Ht} + C_{Ht}^* + I_t \quad (47)$$

We assume that the rest of the world allocates proportion θ_t^* of its wealth W_t^* in the home country and the remaining proportion in the foreign asset. θ_t^* is defined in a

similar way to θ_t

$$\theta_t^* = \bar{\theta}^* \mathcal{E}_t \left(\frac{R_{t+1}}{R_{t+1}^* \frac{E_{t+1}}{E_t}} \right)^\zeta \quad (48)$$

Home bias for the foreign household implies that, in steady state, $0 \leq \bar{\theta}^* < \frac{1}{2}$, and so $\bar{\theta} > \bar{\theta}^*$. We assume that the supply of the foreign asset is positive, constant, and can be larger than the steady state supply of the home asset (reflecting the size of the foreign sector relative to the home country).

Equilibrium conditions for the home and foreign asset then imply

$$Q_t K_{t+1} \frac{1}{E_t} = \theta_t W_{t+1} + \theta_t^* W_{t+1}^* \quad (49)$$

$$\Lambda \bar{K} = (1 - \theta_t) W_{t+1} + (1 - \theta_t^*) W_{t+1}^* \quad (50)$$

where $\bar{K}$ equals the steady state value of K_{t+1} and $\Lambda \geq 1$. The term $Q_t K_{t+1} \frac{1}{E_t}$ on the left-hand side of (49) represents the foreign value of home assets (recall that wealth is defined in terms of foreign goods).

By solving (49) and (50) simultaneously, it is straightforward to show that, in the original steady state, home and foreign wealth are given by $\bar{W}$ and $\bar{W}^*$ where

$$\bar{W} = \bar{K} \frac{(1 - \bar{\theta}^*) - \bar{\theta}^* \Lambda}{\bar{\theta} - \bar{\theta}^*} \quad (51)$$

$$\bar{W}^* = \bar{K} \frac{\bar{\theta} \Lambda - (1 - \bar{\theta})}{\bar{\theta} - \bar{\theta}^*} \quad (52)$$

Under home asset bias (i.e. $\bar{\theta} > \bar{\theta}^*$), if a negative productivity shock at home permanently lowers the stock of home assets to $\phi \bar{K}$ for some $\phi \in (0, 1)$ (that is, $\phi \bar{K} = \frac{\tilde{K}}{E}$, where a $\sim$ denotes the new steady state level), then it can be shown that, in the new

steady state, home wealth $\widetilde{W}$ decreases, while foreign wealth $\widetilde{W}^*$ increases

$$\widetilde{W} = \overline{K} \frac{\phi(1 - \bar{\theta}^*) - \bar{\theta}^* \Lambda}{\bar{\theta} - \bar{\theta}^*} < \overline{W} \quad (53)$$

$$\widetilde{W}^* = \overline{K} \frac{\bar{\theta} \Lambda - \phi(1 - \bar{\theta})}{\bar{\theta} - \bar{\theta}^*} > \overline{W}^* \quad (54)$$

If home investors wish to hold a fixed proportion of their wealth in excess of 50% in the home asset and if the home asset becomes scarcer, then the equilibrium outcome must be that home wealth declines. This then has important implications for the exchange rate that we examine in the simulations in the next section.

3.6 Model summary

The non-linear model consists of equations (31), (33)-(36), (38), (40)-(50). These equations determine the equilibrium dynamics of the variables

$$\{Y_t, R_t, K_t, Q_t, I_t, C_t, E_t, C_{Ht}, C_{Ft}, C_{Ht}^*, P_t, P_{Ht}, P_{Ft}, W_t, W_t^*, \theta_t, \theta_t^*\}_{t=0}^{\infty}$$

given some exogenous processes for the variables A_t and R_t^* .

In order to simplify the analysis we log-linearise⁸ and condense the system into the

⁸ $\bar{x}$ denotes the steady state level and $\hat{x}$ denotes the log-deviation from that steady state $\hat{x} \approx \log(\frac{x}{\bar{x}})$.

following equations (see Appendix 3 for derivation)

$$\mathcal{E}_t(\hat{C}_{t+1} - \hat{C}_t) = \mathcal{E}_t(\bar{\theta}\hat{R}_{t+1} + (1 - \bar{\theta})(\hat{R}_{t+1}^* + \hat{E}_{t+1} - \hat{E}_t)) \quad (55)$$

$$\hat{Y}_t = \hat{A}_t + \alpha\hat{K}_t \quad (56)$$

$$\hat{R}_t = -\hat{Q}_{t-1} + \frac{(1 - \delta)}{\bar{R}}\hat{Q}_t + \left(1 - \frac{1 - \delta}{\bar{R}}\right)(\hat{Y}_t - \hat{K}_t) \quad (57)$$

$$\hat{K}_{t+1} = (1 - \delta)\hat{K}_t + \delta\hat{I}_t \quad (58)$$

$$\hat{Q}_t = \xi(\hat{K}_{t+1} - \hat{K}_t) \quad (59)$$

$$\bar{Y}\hat{Y}_t = \gamma\bar{C}\hat{C}_t + (1 - \gamma)\bar{C}(\gamma\eta + \mu)\hat{E}_t + \bar{I}\hat{I}_t \quad (60)$$

$$\begin{aligned} \bar{K}(\hat{Q}_t + \hat{K}_{t+1} - \hat{E}_t) &= \frac{\bar{\theta}\bar{W}\hat{W}_{t+1} + \bar{\theta}^*\bar{W}^*\hat{W}_{t+1}^*}{+2\zeta\mathcal{E}_t(\hat{R}_{t+1} - \hat{R}_{t+1}^* - \hat{E}_{t+1} - \hat{E}_t)} \end{aligned} \quad (61)$$

$$\begin{aligned} 0 &= (1 - \theta)\bar{W}\hat{W}_{t+1} + (1 - \bar{\theta}^*)\bar{W}^*\hat{W}_{t+1}^* \\ &\quad - 2\zeta\mathcal{E}_t(\hat{R}_{t+1} - \hat{R}_{t+1}^* - \hat{E}_{t+1} - \hat{E}_t) \end{aligned} \quad (62)$$

$$\begin{aligned} \hat{W}_{t+1} &= \frac{\bar{C}}{\bar{W}}(\hat{E}_t - \hat{C}_t) + (1 - \alpha)\frac{\bar{Y}}{\bar{W}}(\hat{Y}_t - \hat{E}_t) \\ &\quad + \bar{R}\hat{W}_t + \bar{\theta}\bar{R}(\hat{R}_t - \hat{E}_t + \hat{E}_{t-1}) + (1 - \bar{\theta})\bar{R}\hat{R}_t^* \end{aligned} \quad (63)$$

Equations (55)-(63) describe the equilibrium dynamics, up to a first-order approximation, of the variables

$$\{\hat{Y}_t, \hat{R}_t, \hat{K}_t, \hat{Q}_t, \hat{I}_t, \hat{C}_t, \hat{E}_t, \hat{W}_t, \hat{W}_t^*\}_{t=0}^\infty$$

given exogenous processes for $\hat{A}_t$ and $\hat{R}_t^*$. Notice that this model, up to a first-order approximation, is analogous to the model in section 2, which implies that the justifications for portfolio bias developed in that section can apply here.

What replaces UIP in this model? As in all the other Chapters, the exchange rate is determined jointly in general equilibrium by (i) goods market equilibrium and (ii) asset market equilibrium conditions. However, unlike in Chapter 1, the exchange rate

Table 2: Parameter calibration and steady state values

Parameter		Value
Capital share of income α		0.35
Discount factor β		0.99
Depreciation rate δ		0.025
Cost of capital adjustment ξ		15
Home bias in goods consumption γ		0.85
Price elasticity of substitution in home/foreign goods η, μ		2.0
Steady state proportion of home portfolio in home asset $\bar{\theta}$		0.75
Steady state proportion of foreign portfolio in home asset $\bar{\theta}^*$		0.05
Foreign asset supply scaling factor Λ		5.0
Elasticity of substitution between home/foreign assets ζ		0.1
Permanent productivity shock $\hat{A}$		-3%
Foreign asset rate of return R^*		$\bar{R}$ (i.e. $\hat{R}^* = 0$)
Steady state variable	Calculation	Value
Output $\bar{Y}$	-	10
Interest rate $\bar{R}$	$\bar{R} = 1/\beta$	1.0101
Capital stock $\bar{K}$	$\bar{K} = \frac{\alpha \bar{Y}}{\bar{R} - (1-\delta)}$	99.7122
Investment $\bar{I}$	$\bar{I} = \delta \bar{K}$	2.4928
Productivity $\bar{A}$	$\bar{A} = \frac{\bar{Y}}{\bar{K}^\alpha}$	1.9973
Consumption $\bar{C}$	$\bar{C} = \bar{Y} - \bar{I}$	7.5072
Home wealth $\bar{W}$	$\bar{W} = \bar{K} = \frac{-\bar{C} + (1-\alpha)\bar{Y}}{1-\bar{R}}$	99.7122
Foreign wealth $\bar{W}^*$	$\bar{W}^* = \Lambda \bar{K}$	498.5612

in the asset market equilibrium is not modelled simply as the uncovered interest parity condition. Instead of a single equation in the asset market, the UIP condition is replaced by a set of equations (the asset equilibrium conditions and the evolution of wealth (61)-(63)) that determine the rate of change of the exchange rate necessary to keep investors satisfied with their asset holdings, for given levels of portfolio bias.

4 Simulations and model properties

We have built a simple model of an open economy in which households exhibit portfolio bias. We now test the response of this economy to aggregate productivity shocks.

4.1 Parameterisation

We parameterise the model (equations (55) to (63)) using the values in table 2 which also allow us to compute the relevant steady state values of model variables

- $\alpha, \beta, \delta, \xi$. The values used for for these parameters are standard in the literature (e.g. Cooley, Hansen and Prescott, 1995; Bernanke, Gertler and Gilchrist, 1999).
- γ . We choose a value of 0.85 for the degree of home bias in goods consumption. While there is clear consensus that there is home bias in trade, it is not clear how great it is. Estimates of this parameter for North America and Europe are typically around 0.9 (Helliwell 1998) (although some estimates range as low as 0.7 [Wei 1998]). Our choice represents a midpoint of this range..
- η, μ . We choose a value of 2 for the elasticity of demand between home and foreign goods. There is no clear consensus on the value of this parameter and our choice is a compromise between the ranges in the literature. Anderson and van Wincoop (2004), for instance, report a range of 3 to 6 whereas other authors use lower values (Backus, Kehoe and Kydland [1994] and Engel and Matsumoto [2009] use $\eta = 1.5$; Ueda [2012] and Kuralbayeva and Vines [2009] use $\eta = 1$).
- $\bar{\theta}$. We choose a value of $\bar{\theta} = 0.75$, which implies that households hold three-quarters of wealth at home. This is a plausible value for home bias in advanced economies and is the value chosen by Kuralbayeva and Vines (2009).

- $\bar{\theta}^*, \Lambda$. We set $\bar{\theta}^* = 0.05$, which implies that the foreign sector exhibits a greater degree of portfolio bias (reflecting the small size of home relative to the rest of the world). The scaling parameter $\Lambda = 5$ is chosen to ensure that home net wealth is equal to zero in steady state $\bar{W} = \bar{K}$. Results are robust to the values of $\bar{\theta}^* \in [1\%, 49\%]$ (i.e. as long as foreigners exhibit home bias as well).
- ζ . The elasticity of substitution between home and foreign assets is set at 0.1, following Kuralbayeva and Vines (2009).
- $\hat{A}$. The shock we simulate is a permanent 3% fall in TFP. We also consider a temporary negative productivity shock and a permanent increase in TFP.

4.2 Baseline simulation – a negative productivity shock

We present the results of our baseline simulation of a permanent 3% fall in productivity in figure 6 (figures are towards the end of this section). We consider the response of each of the variables in turn.

Production (rows 1-2 of figure 6)

Home output Y immediately falls in line with the productivity shock and it continues to decline because capital decumulates. Because capital is now less productive, the demand for capital goods declines, which causes the price of capital Q to fall initially. Q then recovers as the subsequent decumulation of capital raises the marginal product of each remaining unit of capital. Capital goods producers choose investment I in response to the price of capital and so I falls initially before recovering. At the new steady state I has decreased because the stock of capital is smaller and so less investment is required. As a result of the fall in investment, capital K decumulates to a lower long-run level.

The return on home assets R falls because the marginal product of home capital decreases. R then recovers as capital decumulates and the marginal product rises. Notice that R initially shoots down and then after very few periods has spiked back up. This is because the price of capital Q is always rising along the adjustment path, which means that investors enjoy a capital gain on home assets that compensates for the slow adjustment of the capital stock⁹. The excess return on home assets R_X falls and departs from zero, unlike in the case with uncovered interest parity, because assets in this model are not perfect substitutes.

Home wealth (row 3 of figure 6)

Recall from equation (53) that, because of the bias in portfolio allocation that we have assumed, a decline in the home capital stock and thus a decline in the supply of home assets (while leaving the supply of foreign assets unchanged) means that, at the new steady state, home wealth W decreases.

If the supply of the home asset declines (while the supply of the foreign asset remains unchanged), the home country's share of world assets falls. There are now fewer home assets than there were previously. However, home investors still wish to hold a fixed proportion of their wealth that is greater than 50% in the home asset (due to portfolio bias). Hence in equilibrium it must be the case that home wealth falls. We observe this in the third row of figure 6. Not only does home wealth decline, so does net home wealth (defined as home wealth minus liabilities $N_{t+1} \equiv W_{t+1} - Q_t K_{t+1} \frac{1}{E_t}$).

⁹That is, the fact that there is a price of capital means that there is another jump variable and so the burden of adjustment on the interest rate R is shared. The higher the cost of capital adjustment ξ , the greater the burden of adjustment on Q and the smaller the burden on R .

National savings and current account (rows 4-5 of figure 6)

This leads to the question of how the decrease in W is achieved. The main avenue through which home wealth can decumulate is by decreasing national savings. This implies that the home country runs a current account deficit. Hence in the fourth row of figure 6 exports C_H^* fall by more than imports C_F and aggregate consumption C , pushing the current account into deficit, as seen in the fifth row of figure 6. This deficit then closes as the fall in demand for home goods causes their price to decrease (i.e. the exchange rate begins to depreciate after the initial jump). Aggregate home consumption C decreases in the long-run in response to the fall in home wealth. The net international investment position (defined here as the cumulative sum of current account balances) decreases, indicating that the home country is dissaving.

So, the main avenue through which home wealth decreases is via an accumulation of current account deficits. However, we should not neglect the role of *valuation effects*. Recall that the country's wealth is denominated in foreign goods and the return on the home country's investments is denominated in home goods. This means that a depreciation of the home exchange rate from one period to the next lowers the foreign value of home investment, which also lowers home wealth¹⁰. With these considerations in mind, we can then interpret the behaviour of the real exchange rate.

Exchange rates under home bias (final panel of figure 6)

So, in presence of home bias, asset market equilibrium requires that home net wealth decumulate after a negative productivity shock. This is why the exchange rate E

¹⁰To be specific, one unit of home capital yields a return of $R_t \frac{E_{t-1}}{E_t}$ foreign goods and so a depreciation of the exchange rate $\frac{E_{t-1}}{E_t} < 1$ lowers the value of home capital income, which lowers home net wealth.

initially over-appreciates and overshoots its long-run level. This causes the exchange rate to be over-valued (relative to its long-run equilibrium level) all along the adjustment path and hence gives rise to the required current account deficit (discussed above) that brings about the necessary fall in home net wealth. The larger the decrease in home net wealth required by the asset equilibrium conditions, the greater the initial overshoot of the exchange rate.

After the initial overshooting, the exchange rate then gradually depreciates to the new long-run level. This per-period depreciation along the adjustment path gives rise to negative valuation effects by lowering the foreign value of the return on home investment each period. This reinforces the decumulation of home net wealth caused by the negative current account. Furthermore, this short-run per-period depreciation needs to be protracted because the stock of capital (and hence the stock of home net wealth) is slow to adjust. That is, the home country cannot lower its net wealth to the new long-run level immediately and so these negative valuation effects must be spread out over the adjustment path.

Hence, as seen in the final panel of figure 6, the exchange rate initially over-appreciates and overshoots its long-run level before gradually depreciating to this level. (The new long-run level of the exchange rate is appreciated relative to the starting point. This is because the supply of home goods has permanently declined and so, in order to clear the goods market in the long run, the relative price of home goods must rise and so the exchange rate appreciates.)

A structural/causal view of exchange rate movements

The description above in this section has so far been a *reduced form* view of how wealth and the exchange rate must move so as to ensure equilibrium conditions are satisfied.

The *structural form* view of how these movements are caused is straightforward. Because home capital becomes less productive, home firms decumulate the capital stock and so the supply of the home asset declines. Because the home asset becomes relatively scarcer, biased investors¹¹ crowd into the home asset, causing financial inflows and an initial appreciation of the exchange rate. This occurs until the point at which the home exchange rate is sufficiently over-valued relative to its long-run equilibrium level. This is the point where the subsequent per-period depreciation of the exchange rate makes the home asset unattractive enough to dissuade even biased investors from further accumulating it. At this point financial inflows stop, outflows resume, and so the exchange rate gradually depreciates to its long-run level. The changes in wealth required by the asset equilibrium conditions are caused by the exchange rate movements: the over-valuation of the exchange rate along the adjustment path causes net national savings to fall (imports rise and exports fall, *ceteris paribus*).

Put differently, because assets are imperfectly substitutable (equivalently, because investors are biased), the fall in the supply of the home asset causes there to be excess demand for the home asset even though its return has fallen. In order to clear the excess demand for the home asset, the excess return on the home asset has to become sufficiently negative. So, the exchange rate has to depreciate along the adjustment path before biased investors find the home asset unattractive. Thus investors keep flowing into the home country (thus causing the initial overshooting appreciation) until the point where the subsequent depreciation lowers the home excess return sufficiently for biased investors to be indifferent between home and foreign assets. Recall from Chapter 1 that an appreciated long run level combined with a short run depreciating rate of change implies an initial overshooting appreciation of the exchange rate.

¹¹Home investors prefer home assets over foreign assets and even foreign investors wish to hold a fixed fraction of their wealth in the home asset.

An algebraic treatment of exchange rate movements

The analysis in this subsection can be given an algebraic treatment. The key variable here is home net wealth at the end of period t , $\widehat{N}_{t+1}$, defined as wealth minus total liabilities

$$\widehat{N}_{t+1} \equiv \widehat{W}_{t+1} - (\widehat{Q}_t + \widehat{K}_{t+1} - \widehat{E}_t) \quad (64)$$

With some algebraic manipulation¹², we can express home net wealth as

$$\begin{aligned} \widehat{N}_{t+1} = & \underbrace{\frac{1}{\beta} (1 - \bar{\theta}) \widehat{N}_t}_{\text{inherited from previous period}} + \underbrace{\frac{\bar{\theta} (1 - \bar{\theta})}{\beta (1 - \bar{\theta}^*)} (\widehat{N}_t - \Delta \widehat{E}_t)}_{\text{valuation effect}} \\ & + \underbrace{\frac{1 - \bar{\theta}}{1 - \bar{\theta}^*} \left\{ \begin{aligned} & \left(\frac{1}{\beta} (1 + \bar{\theta} - \bar{\theta}^*) + \bar{C}/\bar{W} - (1 - \alpha) \bar{Y}/\bar{W} \right) \widehat{E}_t \\ & - \bar{C}/\bar{W} \widehat{C}_t + \left((1 - \alpha) \bar{Y}/\bar{W} + \theta/\beta \right) \widehat{Y}_t \end{aligned} \right\}}_{\text{net national savings}} \end{aligned} \quad (65)$$

Equation (65) defines home net wealth as the sum of three terms. The first term, $\frac{1}{\beta} (1 - \bar{\theta}) \widehat{N}_t$, is a measure of wealth inherited from last period that was allocated in the foreign asset, scaled up by the steady state rate of return $\frac{1}{\beta}$. The second term represents the portion of wealth inherited from last period that was allocated in the home asset, scaled up by the interest rate $\frac{1}{\beta}$, and augmented by the valuation effect arising from the rate of change of the exchange rate $\Delta \widehat{E}$. The third term represents net savings (income less consumption).

(65) shows that an *appreciated level* of the exchange rate ($\widehat{E} \downarrow$), lowers net national

¹²We combine (61) and (62) to eliminate $\widehat{W}^*$, and substitute into the expression in (64). Using (63), and (57) to eliminate $\widehat{W}$ and $\widehat{R}$ gives an expression for $\widehat{N}$. To make it more tractable for analysis, we set $\delta = 1$ in order to abstract from the effects of inherited capital goods from the previous period. This gives us equation (65). The equation with δ not fixed to one has similar properties.

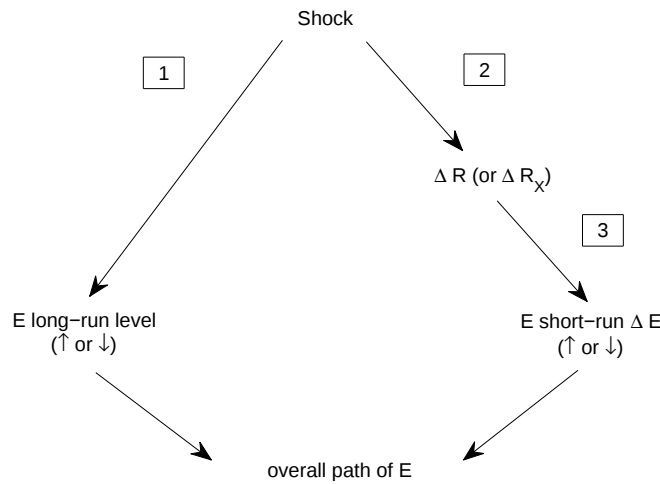
savings indirectly by increasing home aggregate consumption $\hat{C}$ (since foreign imports are cheaper), and directly by increasing the foreign value of home consumption. (65) also shows that a *per-period depreciation* of the exchange rate ($\Delta\hat{E} \uparrow$) also lowers home net wealth by lowering the foreign value of the return on home investment. (65) thus shows that in order for $\hat{N}$ to fall, we need a combination of a per-period depreciation of the exchange rate ($\Delta\hat{E} \uparrow$) and an appreciated level of the exchange rate ($\hat{E} \downarrow$). An initial overshooting appreciation combined with a subsequent gradual depreciation is consistent with this requirement.

Exchange rate determination summary (figure 4)

For the purpose of continuity, we can map the exchange rate movement described above to the familiar schematic seen in Chapter 1, here reproduced in figure 4. Consider the first arrow. In the long run, the exchange rate is appreciated in order to clear goods markets since the supply of the home good declines.

Consider the second arrow. The shock causes the home asset to become relatively scarcer (home capital decumulates). Biased investors crowd into this asset (even though its return has fallen in absolute terms). The excess return R_X on this asset must become sufficiently negative in order to clear the excess demand for this asset. The third arrow follows from the second. In order to make the excess return R_X negative, the exchange rate depreciates along the adjustment path. Together, an appreciated long run level and a per-period depreciation along the adjustment path imply that the exchange rate initially appreciates and overshoots its long-run level before gradually depreciating back to this level (recall table 1 from the Introduction).

Figure 4: Exchange rate determination



Comparison with perfect asset substitutability (UIP)

The red lines in figure 6 illustrate the responses of variables in a model with the uncovered interest parity condition. This is the model in Chapter 1 with $\phi = 1$ ¹³. It is clear that the initial jump of the exchange rate is larger under home bias than under perfect substitutability (UIP). The reason for this is straightforward. Under perfect substitutability, the exchange rate moves so as to equalise the common currency returns on home and foreign assets. So, after a negative shock where the home asset return falls, the exchange rate appreciates along the adjustment path. Combined with a long-run appreciated level of the exchange rate, this thus implies initial undershooting and hence a small initial jump and milder volatility.

On the other hand, when assets are imperfect substitutes, the excess return on home

¹³The fact that the model in this Chapter does not have an endogenous discount factor does not mean that it is not comparable with the model in Chapter 1. We show in Appendix 5 that endogenising the discount factor in the model in this Chapter only changes the quantitative results very slightly. Schmitt-Grohe and Uribe (2003) note that inducing stationarity through the endogenous discount factor does not alter dynamics significantly. In this Chapter, because wealth is pinned down by the capital stock, a unique level of steady state consumption is determined. Hence, this model is stationary and adding an endogenous discount factor does not affect the results significantly.

assets R_X must become sufficiently negative before biased investors are willing to stop accumulating home assets. Hence the exchange rate depreciates along the adjustment path in the short run. Combined with an appreciated long-run level of the exchange rate, this thus implies initial overshooting and hence a larger initial jump and greater volatility. Note that, under home bias, the exchange rate, in response to this productivity shock, moves in the opposite direction to that predicted by UIP (i.e. depreciating rather than appreciating along the adjustment path). Froot and Thaler (1990) note that a large number of studies make this same observation contrary to the UIP condition.

From a *reduced form* view of the model, it is also clear why home bias increases exchange rate volatility after productivity shocks. When investors exhibit bias, their wealth must adjust in equilibrium after these shocks. These changes in wealth are brought about by the exchange rate causing current account surpluses or deficits (by remaining under- or over-valued relative to long run levels). Hence under portfolio bias, there is an additional burden of adjustment on the exchange rate and so we would expect that its volatility is magnified.

As we did in Chapter 1, we can compare the implied second order moments of this model with the data. In table 3, we report again the standard deviations of real exchange rates estimated by Chari, Kehoe and McGrattan (2002) using quarterly data. In the bottom panel, we report the implied standard deviations for different values of the capital adjustment cost ξ and the size of the technology shock (measured in terms of change in output on impact)¹⁴. These results confirm what is apparent from the simulations, that the volatility of the exchange rate is greater in this model with home bias than in the model with UIP. Furthermore, this higher volatility comes closer to matching the observed volatility of real exchange rates. Of course, for reasonably sized shocks

¹⁴We impose an AR(1) structure on $\hat{A}$ and choose an autoregressive coefficient of 0.93 (following Peersman and Straub [2004]).

Table 3: Comparing standard deviations of the real exchange rate

Estimated standard deviation of E					
country relative to US					
Austria	Denmark	Finland	France	Germany	Italy
7.93	8.00	7.71	7.95	8.06	7.80
Netherlands	Norway	Spain	Switzerland	UK	Europe
7.99	6.08	8.42	8.83	7.89	7.52

Source: Chari, Kehoe and McGrattan (2002)

Model-derived standard deviation of E			ξ			
			0.1	1	10	100
ΔY on impact	0.1%	home bias	0.08	0.08	0.10	0.14
		<i>UIP</i>	<i>0.07</i>	<i>0.06</i>	<i>0.07</i>	<i>0.08</i>
	1%	home bias	0.83	0.84	1.02	1.42
		<i>UIP</i>	<i>0.66</i>	<i>0.63</i>	<i>0.66</i>	<i>0.77</i>
	3%	home bias	2.49	2.51	3.06	4.26
		<i>UIP</i>	<i>1.98</i>	<i>1.90</i>	<i>1.98</i>	<i>2.31</i>
	5%	home bias	4.16	4.18	5.09	7.10
		<i>UIP</i>	<i>3.31</i>	<i>3.16</i>	<i>3.30</i>	<i>3.85</i>
	7%	home bias	5.82	5.86	7.13	9.94
		<i>UIP</i>	<i>4.63</i>	<i>4.43</i>	<i>4.62</i>	<i>5.39</i>

to productivity (1% or 3%) and the adjustment cost (~ 10), the implied volatility is still much lower than the observed volatility. There are still other frictions and shocks that we are not capturing in this model. Nonetheless, we can still tentatively draw the conclusion that home bias generates a higher and more plausible degree of real exchange rate volatility than the UIP condition.

4.3 More simulations – a temporary shock and a positive shock

A temporary negative shock

For completeness, we also consider a temporary productivity shock. We impose an AR(1) structure on $\hat{A}$ and choose an autoregressive coefficient of 0.93 (following Peers-

man and Straub [2004]). Results are robust for values of this coefficient above 0.5. These simulations are shown in figure 7. We can attach the same interpretation here as for the baseline permanent shock. However, because this is a temporary shock, its effects have to be reversed. So, in the second phase of the simulations, we observe variables changing direction.

Output falls as a result of the shock but recovers as the shock dissipates. The process is relatively slow because of the slow decumulation and reaccumulation of capital, and because of the persistence of the shock. The hump-shaped path of the capital stock implies that the price of capital and investment initially drop, before rising above steady state and then returning to zero. The return on the home asset thus spikes down as before, but recovers much more quickly.

Home wealth falls temporarily. In order to bring this about, exports initially fall before rising above zero. This gives rise to a current account deficit and then a current account surplus to erase the effects of the initial deficit.

So, the exchange rate initially appreciates, bringing the current account into deficit, before depreciating above its long-run level (of zero) in order to bring about current account surpluses to reverse the initial deficits.

A permanent positive shock

It is straightforward to consider the opposite case to the baseline simulation in which the the home country experiences a permanent increase in productivity. We consider the the case of a permanent 3% rise in $\hat{A}$ and illustrate the results in figure 8. The behaviour of the variables in the first six panels of figure 8 is well understood. A positive productivity shock causes output to immediately jump up before gradually increasing

further as capital accumulates. The price of capital jumps up because capital goods become more productive (and so there is excess demand for capital), which causes investment to rise. The capital stock rises and the return on home assets spikes up.

Because the relative value of outstanding home assets in the world increases, and because there is home bias in portfolio allocations, home wealth must increase at the new steady state. This is simply the opposite of what occurred under the negative shock. In order for the home country to accumulate wealth, it runs a current account surplus, as the fourth and fifth rows of figure 8 show (exports rise by more than imports). Hence the exchange rate (final panel) must initially over-depreciate and overshoot in order to be under-valued (relative to its long-run level) along the adjustment path. The exchange rate then appreciates along the adjustment path to its long-run level: this subsequent gradual appreciation generates positive valuation effects that complement the positive current account surpluses.

Structurally, what happens is that the home asset becomes relatively more abundant. Since assets are imperfectly substitutable, there is now an excess supply of home assets. Biased investors thus wish to divest of this asset and allocate more of their portfolios to the now relatively scarcer foreign asset. Financial outflows occur, causing the exchange rate to depreciate until it is sufficiently under-valued. This is where the subsequent per-period appreciation of the exchange rate sufficiently raises the excess return on home assets to make these assets attractive enough for investors to stop decumulating them. Outflows stop, inflows resume, and the exchange rate gradually appreciates to its long-run level. Wealth movements follow from exchange rate movements: the under-valuation of the exchange rate along the adjustment path gives rise to a current account surplus and thus a rise in home wealth.

As in the case of the negative shock, the behaviour of the exchange rate is more volatile

than in the case with perfect substitutability (UIP). This is because the exchange rate has to perform the extra role of inducing changes in home and foreign wealth between the original and new steady states. Hence the burden of adjustment on the exchange rate is larger and the initial jump of the exchange rate increases in size. As in the case of the negative shock, imperfect asset substitutability predicts that the exchange rate moves along the adjustment path in the opposite direction to that predicted by UIP.

4.4 Comparison with Blanchard, Giavazzi and Sa (2005)

We have found that, with home asset bias, the exchange rate would typically overshoot in response to a productivity shock. This differs from a key paper on the effect of home bias on exchange rates by Blanchard, Giavazzi and Sa (2005). Blanchard *et al.* (and Kuralbayeva and Vines [2009]) argue that, under home bias, the exchange rate would move slowly and gradually to its new long-run level (i.e. undershooting) contrary to the overshooting that we predict in our model.

The reason for this divergence in our results is that in our model there is a moving stock (and price) of capital. On the other hand, in Blanchard *et al.*, the quantity and price of capital are fixed and so the value of outstanding home assets only moves due to changes in the exchange rate. With the quantity and price of capital fixed this would mean that the relative value of home assets *rises* after a permanent fall in productivity because in the long run the exchange rate appreciates (since the supply of home goods declines).

With home bias in asset allocations, this implies that at the new steady state home wealth actually needs to *increase*. The home country needs to run a current account surplus, which is achieved by the exchange rate remaining *under*-valued (relative to

its long-run level). Thus the model of Blanchard *et al.* implies that, after a negative productivity shock, the exchange rate gradually appreciates to its new (appreciated) long-run level, instead of initially overshooting this long-run level as our model predicts.

In the rest of this subsection, we show how the parameterisation of our own model can be manipulated to replicate the results predicted by Blanchard *et al.*. Essentially, we want to choose a calibration that minimises the impact of a moving stock of capital.

The change in the stock of home assets from the original steady state to the new steady state is given by (Tobin's Q is always one in steady state)

$$\frac{\overline{QK}}{\overline{E}} = \frac{\overline{K}}{\overline{E}} \rightarrow \frac{\widetilde{K} \downarrow}{\widetilde{E} \downarrow}$$

where $\widetilde{K} < \overline{K}$ (capital decumulates) and $\widetilde{E} < \overline{E}$ (the exchange rate appreciates). Up to now, the decumulation of capital ($\widetilde{K} \downarrow$) had dominated the appreciation ($\widetilde{E} \downarrow$) and so the total stock of home assets had declined following the negative shock ($\frac{\overline{K}}{\overline{E}} > \frac{\widetilde{K}}{\widetilde{E}}$). But clearly there is a set of parameterisations under which the exchange rate appreciation is large enough to dominate, such that the value of home assets actually rises after a negative productivity shock ($\frac{\overline{K}}{\overline{E}} < \frac{\widetilde{K}}{\widetilde{E}}$). The set of parameterisations that achieves this has these features

- The fall in capital is relatively small. A small capital share of output achieves this $\alpha \downarrow$. We lower α to 0.05.
- The appreciation of the exchange rate at the new steady state is relatively large. A lower elasticity of substitution between home and foreign goods achieves this by increasing the extent to which the exchange rate needs to adjust in order to clear goods markets $\eta \downarrow$. We lower η to 0.1.

All other parameter values remain unchanged (table 2). Under this new calibration, the value of home assets actually increases after a negative productivity shock ($\frac{\tilde{K}}{\tilde{E}} > \frac{\bar{K}}{\bar{E}}$). And so, with home bias in portfolio allocation, home wealth needs to increase in equilibrium¹⁵.

In figure 9 we present the response of the model under this calibration to the same 3% negative fall in productivity as before. There is nothing new to add about the first six panels of figure 9. Turning to the third row: as discussed above, the relative value of home assets has risen in the new steady state, and so, because of home bias, home wealth must also rise.

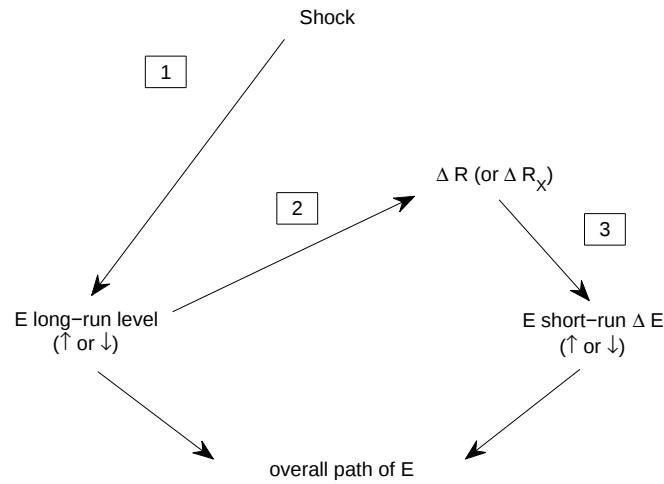
The channel through which these changes in wealth are achieved is by now familiar. Consider the last two rows of figure 9. In order for home wealth to rise, imports and consumption initially fall by more than exports, which causes the home country to run a current account surplus and accumulate a positive net IIP. In order to induce this positive trade balance, the exchange rate initially *undershoots* so that it remains under-valued (relative to its long-run level), before gradually appreciating to the new long-run level.

In summary: the home asset becomes relatively more abundant and so investors, who only wish to hold a fixed fraction of their wealth in this asset divest of it. Financial outflows occur, leading to downward pressure on the exchange rate until it is sufficiently under-valued (relative to its long-run level). This is the point where the subsequent per-period appreciation makes home assets attractive enough for investors to stop further

¹⁵As equation (53) shows, with $\phi > 1$ and home bias ($\theta > \frac{1}{2}, \theta^*$), home wealth increases at the new steady state, while foreign wealth decreases

$$\begin{aligned} \widetilde{W} &= \bar{K} \frac{\phi(1-\theta^*)-\theta^*\Lambda}{\theta-\theta^*} > \bar{W} = \bar{K} \frac{(1-\theta^*)-\theta^*\Lambda}{\theta-\theta^*} \\ \widetilde{W^*} &= \bar{K} \frac{\theta\Lambda-\phi(1-\theta)}{\theta-\theta^*} < \bar{W^*} = \bar{K} \frac{\theta\Lambda-(1-\theta)}{\theta-\theta^*} \end{aligned}$$

Figure 5: Exchange rate determination



decumulating them. In other words, instead of excess demand, a permanent decline in productivity under this parameterisation leads to excess supply of the home asset. To clear this excess supply, the excess return on home assets must become sufficiently positive and so the exchange rate must appreciate along the adjustment path, rather than depreciate.

Hence, with a special class of parameter values (that are chosen so as to diminish the effect of a moving stock of capital), our model can replicate the results of Blanchard *et al.* where home bias leads to gradual and slow adjustment of the exchange rate.

Blanchard *et al.* exchange rate determination summary (figure 5)

Interestingly, this means that the schematic we used above and in the rest of this thesis changes slightly in the case of a Blanchard *et al.* parameterisation. The long-run and short-run changes in the exchange rate become interdependent. See figure 5. The first

arrow remains the same: in the long run the exchange rate appreciates to clear goods markets. But it is the long-run change in the exchange rate that determines the relative supply of the home asset. Because the exchange rate appreciates, the relative value and abundance of home assets rises at the new steady state. Hence (the second arrow) this causes there to be excess supply of the home asset, which is cleared with a positive excess return R_X on the home asset. The third arrow once again follows from the second: in order for R_X to become positive, the exchange rate appreciates along the short-run path. A long-run appreciated level and a short-run per-period appreciation together imply initial undershooting.

Figure 6: Baseline simulation – Permanent fall in productivity

See section 4.2.

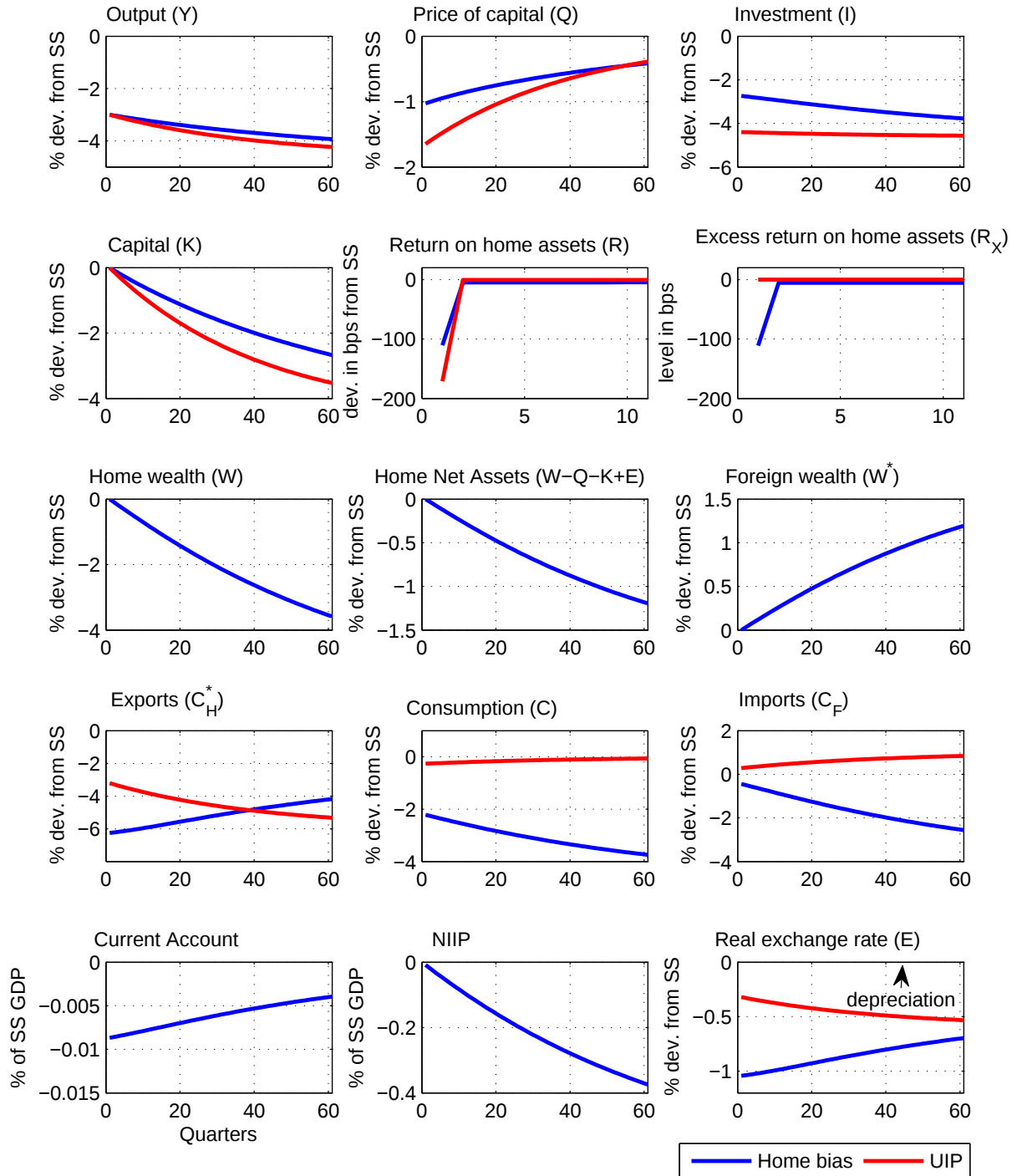


Figure 7: Temporary fall in productivity

See section 4.3.

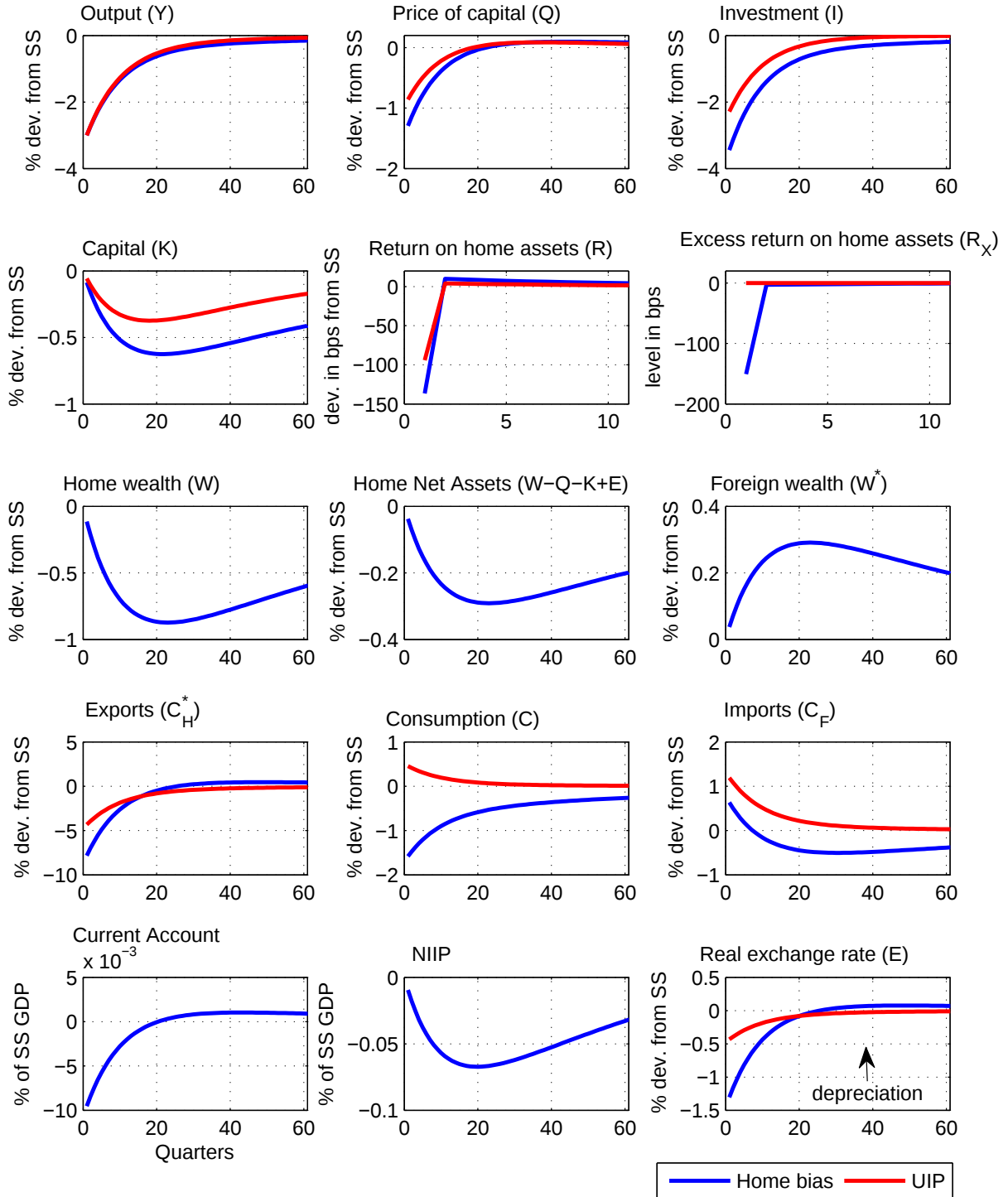


Figure 8: Permanent *rise* in productivity

See section 4.3.

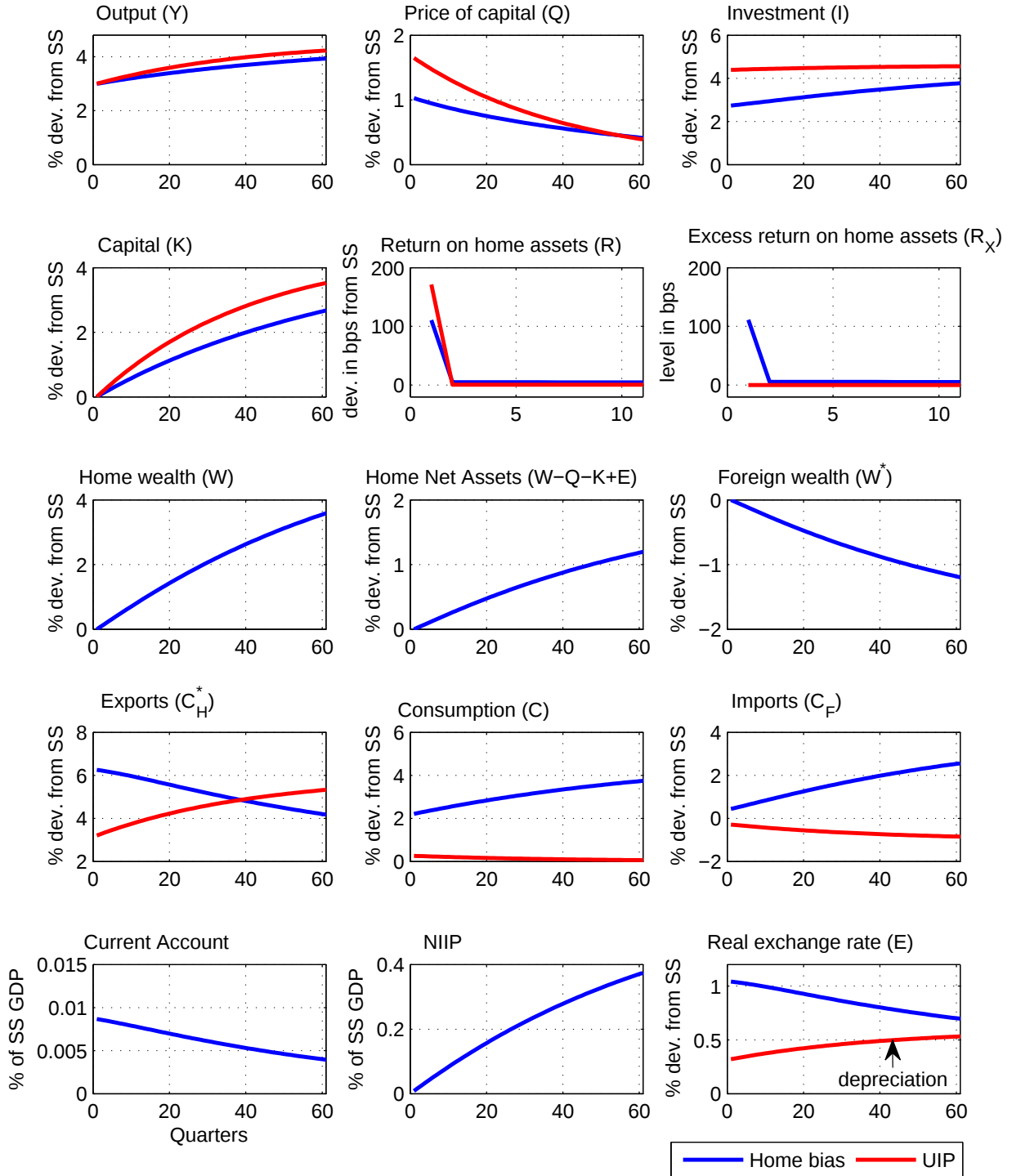
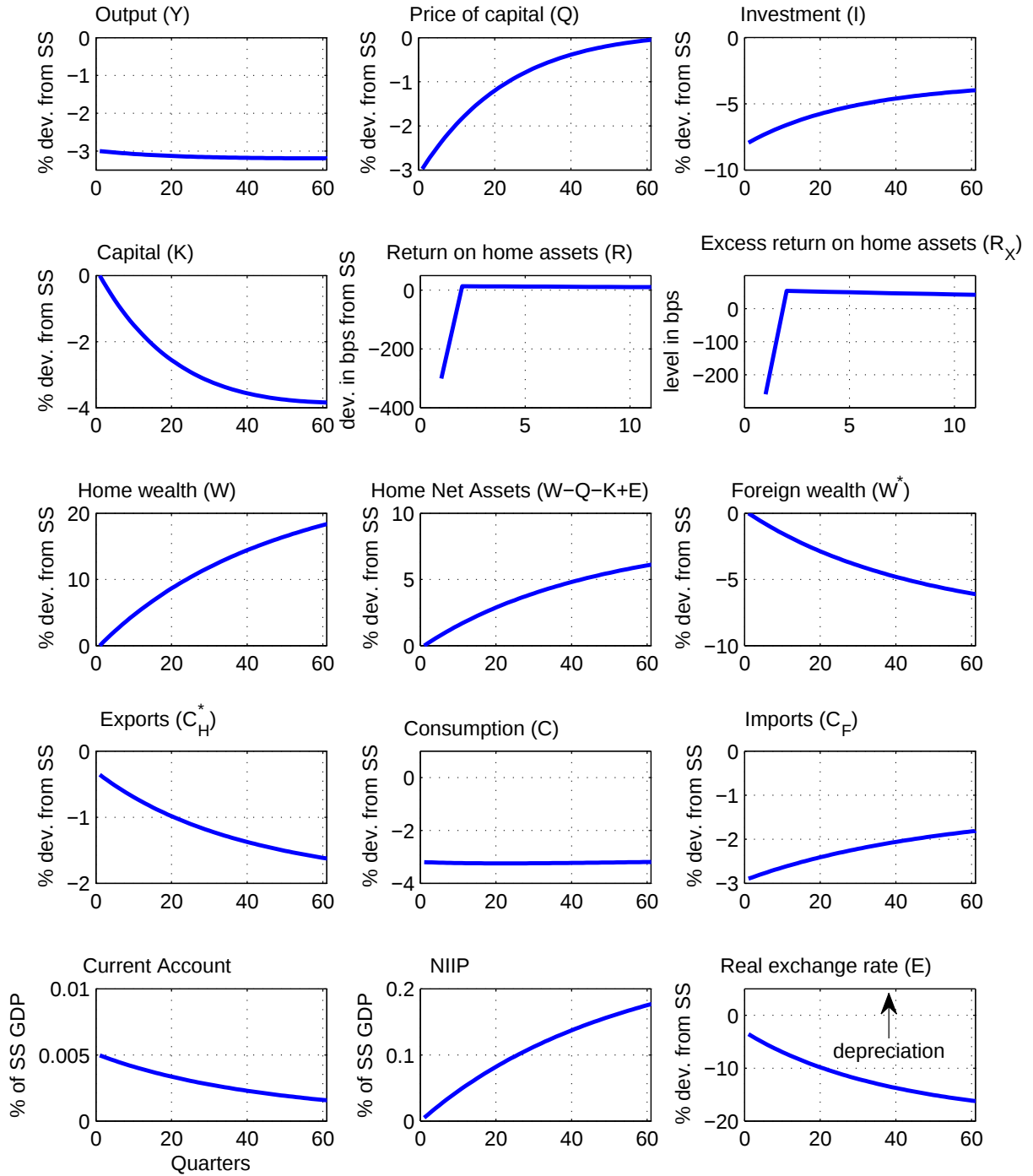


Figure 9: Permanent fall in productivity under Blanchard *et al.*

See section 4.4.



4.5 Phase diagrams

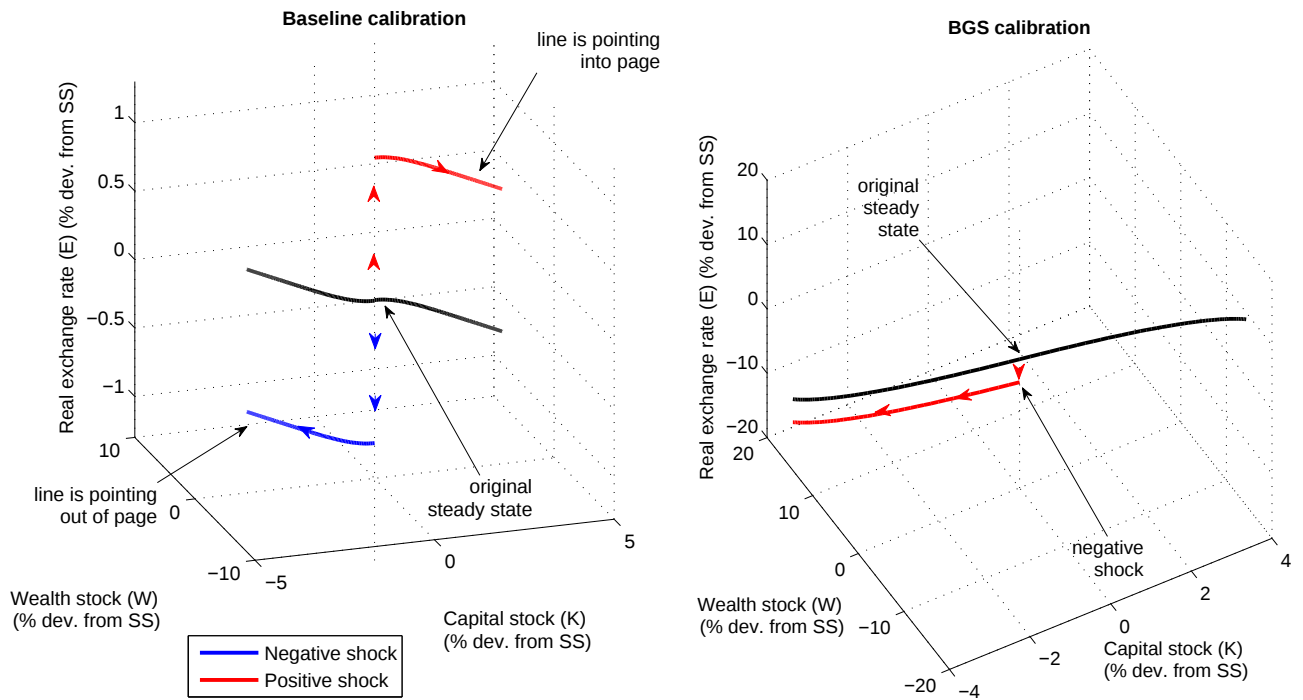
We can represent the results above using phase diagrams in three-dimensional space. By using the numerical solution to the model, we can plot the saddle path of the system as a function of capital (K), wealth (W), and the real exchange rate (E).

Consider the left-hand panel of figure 10 which shows the equilibrium schedule for the system under our baseline calibration. At the original steady state, the stable arm is represented by the black line. Along this black line, as capital increases, so does wealth. This is because, as capital increases, the quantity of home assets increases and so (because of home asset bias) the stock of home wealth must accordingly increase. As home wealth increases, the exchange rate appreciates ($E \downarrow$). This is because, as home wealth rises, the domestic demand for home goods also rises and so the exchange rate appreciates in order to reduce external demand and equilibrate home goods markets.

The case of a permanent fall in productivity is represented by the blue line. At the new steady state, capital, wealth and the exchange rate all decrease and so the original black equilibrium schedule must shift down in order to pass through this new steady state. Hence the exchange rate initially over-appreciates beyond its long-run level. The exchange rate then depreciates to its long-run level, as both capital and wealth decumulate. This corresponds with the simulations in figure 6. The case of a permanent rise in productivity is represented by the red line, which corresponds with the simulations in figure 8.

Consider now the right-hand panel of figure 10. The black line is the equilibrium schedule for the model under the parameterisation to mimic Blanchard *et al.* (see section 4.4). As with the original parameterisation, and for the same reason, as wealth increases the exchange rate appreciates ($E \downarrow$). However, unlike under the original

Figure 10: Phase diagrams



calibration, as capital increases, home wealth decreases. This is because, as capital increases, the supply of the home good rises and so the exchange rate depreciates. This depreciation causes the relative value of the stock of home assets in the world to fall (since, under the Blanchard *et al.* calibration, exchange rate effects dominate changes in the capital stock) and so (because of home asset bias) the stock of home wealth must also fall.

The red line represents the case of a permanent fall in productivity. At the new steady state the exchange rate appreciates and capital falls, but the stock of home wealth rises. The schedule shifts down to pass through this new steady state. The exchange rate thus initially undershoots before gradually appreciating to its long-run level¹⁶.

¹⁶Notice, if the schedule is sufficiently steep, it may have to shift up to pass through the new steady state - this would mean the exchange rate has to initially undershoot so much that it initially depreciates.

5 Discussion

In this section, we synthesise the main results of this Chapter. The main results are

1. In response to productivity shocks, imperfect asset substitutability increases the volatility of the exchange rate compared to the case of perfect substitutability (UIP). Under home bias, the exchange rate typically overshoots its long-run level after productivity shocks, which implies greater volatility than the case of UIP, where the exchange rate typically undershoots. This is seen in figures 6 (negative shock) and 8 (positive shock). If investors are biased, asset markets only clear when expected excess returns deviate sufficiently from zero to equilibrate supply and demand. Along the short-run path, the burden of adjustment on the per-period movement of the exchange rate thus tends to be greater (and have the opposite sign) compared with the case of UIP (where expected excess returns do not deviate from zero).

- E.g. a fall in productivity. Because assets are imperfect substitutes, a fall in the supply of the home asset leads to excess demand for this asset even though its return has fallen. So, to clear this excess demand, the excess return on the home asset R_X must become sufficiently negative so that even biased investors want to stop accumulating home assets. Hence the exchange rate must depreciate along the adjustment path in the short run, which, combined with an appreciated long-run level, implies initial overshooting¹⁷. Under perfect substitutability, the exchange rate appreciates in the short run (in order to equalise the common currency returns of assets, driving excess

¹⁷We have conducted our analysis in a small open economy model for simplicity. In Appendix 7 we show that a symmetric two country model (with each country identical to the home country focused on here) exhibits the same qualitative results.

returns to zero), implying undershooting and hence a smaller initial jump and milder volatility.

- What causes this exchange rate movement after a fall in productivity? Biased investors crowd into the now relatively scarcer home asset, causing financial inflows and exchange rate over-appreciation until the point where the home currency is so over-valued that even biased investors no longer wish to keep accumulating home assets. Outflows then occur and the exchange rate gradually depreciates to its new long-run level.
2. The first result above contradicts the finding of a key paper on imperfect asset substitutability by Blanchard, Giavazzi and Sa (2005). In the Blanchard *et al.* model, following a permanent fall in productivity, the exchange rate would gradually appreciate to its long-run level, rather than initially overshoot as our model predicts. The difference in these predictions arises from the fact that our model contains a moving stock (and price) of capital. In figure 9 we show that under a special parameterisation (chosen so as to diminish the effect of a moving stock of capital), our model can replicate the predictions of the Blanchard *et al.* model.
 3. Even when returns on assets are equal, portfolio bias can arise when the second-order characteristics of assets differ. All else equal, risk averse households prefer assets that provide insurance value against negative shocks to consumption. The simple model in section 2 predicts that, under reasonable parameter values, households exhibit a plausible degree of home asset bias. This re-confirms the result of an extensive theoretical literature (e.g. Heathcote and Perri, 2013) but arguably with a simpler model and fewer assumptions.

As we stated before, another way to interpret the higher exchange rate volatility under home bias (the first result above) is to consider the equilibrium behaviour of wealth

stocks. Given that in steady state home investors wish to hold a fixed fraction of their wealth that is higher than 50% in the home asset (due to home bias) and given that, after the fall in home productivity, there are now fewer outstanding home assets than there were previously, in equilibrium it must be the case that home wealth decreases. The changes in home wealth required by asset equilibrium conditions are brought about by exchange rate movements: the over-valuation of the exchange rate along the adjustment path leads to a running down of national savings (imports rise, exports fall *ceteris paribus*), causing home wealth to decumulate. Hence, with home bias, the exchange rate carries a greater burden of adjustment because it must move so as to bring about the changes in wealth stocks required by asset equilibrium conditions.

It may appear counter-intuitive that the exchange rate is more volatile under imperfect substitutability (certainly Blanchard *et al.* argue the opposite case). But the reason for this is straightforward. Take our baseline case of a fall in productivity that causes a decline in the supply of home assets, hence leading to excess demand. Under UIP, this excess demand clears immediately because the return on the home asset falls and assets are treated as perfect substitutes *ex ante*. Under imperfect substitutability, however, this excess demand persists because investors are biased and are thus undeterred by the fall in the home asset's return. Hence, *without* UIP, the exchange rate has to do more "heavy lifting" to equilibrate supply and demand in asset markets after productivity shocks.

6 Concluding remarks

In this Chapter, we have extended the analysis of Chapter 1 to examine the effect of imperfect asset substitutability, and in particular, portfolio bias, on exchange rates.

We have found that portfolio bias can arise out of parsimonious assumptions due to the difference in the second-order characteristics of assets. We find that imperfect asset substitutability increases exchange rate volatility compared with the case of the uncovered interest parity condition.

To conclude, we discuss some caveats and possible extensions to this Chapter. First, as a simplifying assumption, we had imposed the condition that investors allocate their wealth across assets in proportions described by a simple function θ_t . This is a satisfactory assumption for our purposes because we only consider a first-order approximation of the behaviour of other model variables. However, there is a microfounded way to model portfolio flows. Devereux and Sutherland (2011) provide a method of doing this, which involves finding a third-order approximation of the non-linear model.

Furthermore, a richer account of the drivers of portfolio bias may be appropriate. He and Luk (2013), for instance, include a capital quality shock that drives a wedge between capital and labour income within the same country.

References

- [1] Anderson, James E., & Eric van Wincoop. 2004. Trade costs. *Journal of Economic Literature* 42 (3): 691—751.
- [2] Backus, David K., Patrick J. Kehoe, & Finn E. Kydland. 1994. Dynamics of the trade balance and the terms of trade: the J-curve?. *American Economic Review* 84 (1): 84—103.
- [3] Baxter, Marianne & Urban J. Jermann. 1997. The international diversification puzzle is worse than you think. *American Economic Review* 87 (1): 170—80.
- [4] Blanchard, Olivier, Francesco Giavazzi, & Filipa Sa. 2005. The US current account and the dollar. NBER Working Papers 11137. National Bureau of Economic Research.

-
- [5] Branson, William H. & Dale W. Henderson. 1985. The specification and influence of asset markets. In *Handbook of International Economics* Vol. 2, 749—805, edited by R. W. Jones and Peter Kenen. Elsevier.
- [6] Burnside, Craig, Martin Eichenbaum & Sergio Rebelo. 2008. Prospective deficits and the Asian currency crisis. *Journal of Political Economy* 109 (2001): 1155—97.
- [7] Chang, Roberto & Andres Velasco. 1998. The Asian liquidity crisis. NBER Working Papers 6796. National Bureau of Economic Research.
- [8] Chari, Varadarajan V., Patrick J. Kehoe & Ellen R. McGrattan. 2002. Can sticky price models generate volatile and persistent real exchange rates?. *Review of Economic Studies* 69 (3): 533—63.
- [9] Claus, Iris. 2007. The effects of bank lending in an open economy. *Journal of Money, Credit and Banking* 39 (5): 1213—48.
- [10] ———. 2011. The effects of asymmetric information between borrowers and lenders in an open economy. *Journal of International Money and Finance* 30 (5): 796—816.
- [11] Coeurdacier, Nicolas, Robert Kollmann, & Philippe Martin. 2009. International portfolios with supply, demand and redistributive shocks. In *NBER International Seminar on Macroeconomics 2007*, edited by Richard Clarida and Francesco Giavazzi. Chicago, Illinois: University of Chicago Press.
- [12] ———. 2010. International portfolios, capital accumulation and foreign asset dynamics. *Journal of International Economics* 80 (1): 100—12.
- [13] Coeurdacier, Nicolas, Helene Rey, & Pablo Winant. 2011. The risky steady state. *American Economic Review* 101 (3): 398—401.
- [14] Collard, Fabrice, Harris Dellas, Behzad Diba, & Alan Stockman. 2009. Goods trade and international equity portfolios. School of Economics Working Papers 2009-14, University of Adelaide School of Economics.
- [15] Cooley, Thomas F., Gary D. Hansen, & Edward C. Prescott. 1995. Equilibrium business cycles with idle resources and variable capacity utilization. *Economic Theory* 6 (1): 35—49.
- [16] Corbett, Jenny & David Vines. 1999. Asian currency and financial crises: lessons from vulnerability, crisis and collapse. *The World Economy* 22 (2): 155—77
- [17] Corsetti, Giancarlo, Paolo Pesenti, & Nouriel Roubini. 1999. What caused the Asian currency and financial crisis?. *Japan and the World Economy* 11 (3): 305—73.

- [18] Devereux, Michael B., & Alan Sutherland. Country portfolio dynamics. *Journal of Economic Dynamics & Control* 34 (7): 1325—42.
- [19] ———. 2011. Country portfolios in open economy macro-models. *Journal of the European Economic Association* 9 (2): 337—69.
- [20] Engel, Charles & Akito Matsumoto. 2009. The international diversification puzzle when goods prices are sticky: it's really about exchange-rate hedging, not equity portfolios. *American Economic Journal: Macroeconomics* 1 (2): 155—88.
- [21] French, Kenneth R. & James M. Poterba. 1991. Investor diversification and international equity markets. *American Economic Review* 81 (2): 222—26.
- [22] Froot, Kenneth A. & Richard H. Thaler. 1990. Foreign exchange. *Journal of Economic Perspectives* 4 (3): 179—92.
- [23] Gali, Jordi & Tommaso Monacelli. 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies* 72: 707—34.
- [24] Gertler, Mark, Simon Gilchrist & Fabio Natalucci. 2007. External constraints on monetary policy and the financial accelerator. *Journal of Money, Credit and Banking* 39 (2—3): 295—330.
- [25] Ghironi, Fabio, Jaewoo Lee, & Alessandro Rebucci. 2009. The valuation channel of external adjustment. IMF Working Paper WP/09/275. International Monetary Fund, Washington D.C., December 2009.
- [26] He, Dong & Paul Luk. 2013. A model of Chinese capital account liberalisation. Working Paper No. 12/2013. HKIMR. August 2013.
- [27] Heathcote, Jonathan & Fabrizio Perri. 2013. The international diversification puzzle is not as bad as you think. Working Papers 472, Innocenzo Gasparini Institute for Economic Research (IGIER), Bocconi University.
- [28] Helliwell, John F. 1998. *How much do national borders matter?*. Washington D.C.: Brookings Institution.
- [29] Juillard, Michel. 2011. Local approximation of DSGE models around the risky steady state. wp.communite 0087. University of Teramo Department of Communication.
- [30] Krugman, Paul. 2007. Will there be a dollar crisis? *Economic Policy* 22: 435—67. CEPR, CES and MSH. July, 2007.
- [31] Kuralbayeva, Karlygash & David Vines. 2009. The process by which the dollar will fall: the effect of forward-looking consumers. CEPR Discussion Papers 7325. Centre for Economic Policy Research.

-
- [32] Lane, Philip R. & Gian Maria Milesi-Ferretti. 2007. The external wealth of nations mark II: revised and extended estimates of foreign assets and liabilities, 1970-2004. *Journal of International Economics* 73 (2): 223—50.
- [33] Luk, Sheung Kan & David Vines. 2011. Financial-friction macroeconomics with highly leveraged financial institutions. CEPR Discussion Papers 8576. Centre for Economic Policy Research.
- [34] Meese, Richard A. & Kenneth Rogoff. 1983. Empirical exchange rate models of the seventies: do they fit out of sample?. *Journal of International Economics* 14 (1-2): 3—24.
- [35] ———. 1988. Was it real? The exchange rate-interest differential relation over the modern floating-rate period. *Journal of Finance* 43 (4): 933—48.
- [36] Mercado Jr., Rogelio V. 2013. Emerging Asia equity home bias and financial integration. *International Economic Journal* 27 (4): 497—524.
- [37] Meredith, Guy. 2007. Debt dynamics and global imbalances: some conventional views reconsidered. IMF Working Paper WP/07/4. International Monetary Fund, Washington, D.C., January 2007.
- [38] Obstfeld, Maurice & Kenneth Rogoff. 2001. The six major puzzles in international macroeconomics: is there a common cause?. In *NBER Macroeconomics Annual 2000* (15), edited by Ben S. Bernanke & Kenneth Rogoff. Cambridge, MA: NBER.
- [39] Palacios-Huerta, Ignacio. 2001. The human capital of stockholders and the international diversification puzzle. *Journal of International Economics* 54 (2): 309—31.
- [40] Peersman, Gert & Roland Straub. 2004. Technology shocks and robust sign restrictions in a euro area SVAR. Working Paper Series No. 373, European Central Bank, July.
- [41] Sa, Filipa & Francesca Viani. 2013. Shifts in portfolio preferences of international investors: an application to sovereign wealth funds. *Review of International Economics* 21 (5): 868—85.
- [42] Schmitt-Grohe, Stephanie & Martin Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61 (1): 163—85.
- [43] ———. 2004. Solving dynamic general equilibrium models using a second-order approximation to the policy function. *Journal of Economic Dynamics & Control* 28 (2004): 755—75.
- [44] Tesar, Linda L. & Ingrid M. Werner. 1995. Home bias and high turnover. *Journal of International Money and Finance* 14 (4): 467—92.

-
- [45] Ueda, Kozo. 2012. Banking globalization and international business cycles: cross-border chained credit contracts and financial accelerators. *Journal of International Economics* 86 (1): 1—16.
 - [46] Warnock, Francis E. 2002. Home bias and high turnover reconsidered. *Journal of International Money and Finance* 21 (6): 795—805.
 - [47] Wei, Shang-Jin. 1998. How reluctant are nations in global integration?. NBER Working Papers 5531. National Bureau of Economic Research.

Appendix

1 Deriving the log-linearised model in Section 2

The non-linear model contains the equations (1)-(3), (5)-(14), (16) and (19). Log-linearising these gives

$$\widehat{Y}_t = \widehat{A}_t + \alpha \widehat{K}_t \quad (66)$$

$$\widehat{K}_{t+1} = (1 - \delta) \widehat{K}_t + \delta \widehat{I}_t \quad (67)$$

$$\widehat{R}_t = \left(1 - \frac{1 - \delta}{R}\right) (\widehat{Y}_t - \widehat{K}_t) \quad (68)$$

$$0 = \mathcal{E}_t (\widehat{C}_t - \widehat{R}_{t+1} + \widehat{C}_{t+1}) \quad (69)$$

$$0 = \mathcal{E}_t (\widehat{C}_t - \widehat{R}_{t+1}^* + \widehat{E}_{t+1} - \widehat{E}_t + \widehat{C}_{t+1}) \quad (70)$$

$$\widehat{C}_{Ht} = \widehat{C}_t - \eta (\widehat{P}_{Ht} - \widehat{P}_t) \quad (71)$$

$$\widehat{C}_{Ft} = \widehat{C}_t - \eta (\widehat{P}_{Ft} - \widehat{P}_t) \quad (72)$$

$$\widehat{P}_t = \gamma \widehat{P}_{Ht} + (1 - \gamma) \widehat{P}_{Ft} \quad (73)$$

$$\widehat{P}_{Ht} = 0 \quad (74)$$

$$\widehat{P}_{Ft} = \widehat{E}_t \quad (75)$$

$$\widehat{C}_{Ht}^* = \mu \widehat{E}_t \quad (76)$$

$$\overline{Y} \widehat{Y}_t = \gamma \overline{C} \widehat{C}_{Ht} + (1 - \gamma) \overline{C} \widehat{C}_{Ht}^* + \overline{I} \widehat{I}_t \quad (77)$$

$$\begin{aligned} \widehat{W}_{t+1} = & -\frac{\overline{C}}{\overline{W}} \widehat{C}_t + (1 - \alpha) \frac{\overline{Y}}{\overline{W}} \widehat{Y}_t + \frac{\overline{H} \overline{H} \overline{R}}{\overline{W}} \widehat{R}_{Xt} \\ & + \overline{R} (\widehat{W}_t + \widehat{R}_t^* + \widehat{E}_t - \widehat{E}_{t-1}) \end{aligned} \quad (78)$$

$$\widehat{K}_{t+1} = \widehat{W}_{t+1} \quad (79)$$

(66)-(70), (78)-(79) appear unchanged in the condensed model ((20)-(27)). Substituting (71)-(76) into (77) gives the last equation in the condensed model (47).

2 Deriving the steady state portfolio in Section 2

The second step in the derivations of the steady state portfolio involves finding the state space solution to the model. The model described by the equations (20) to (27) can be further simplified by eliminating $\widehat{K}, \widehat{R}, \widehat{Y}, \widehat{I}$, and using the fact that $\widehat{A}$ and $\widehat{R}^*$ are zero in expectation

$$0 = \mathcal{E}_t \left(\widehat{C}_t - \widehat{C}_{t+1} - (1 - \alpha) \left(1 - \frac{1 - \delta}{\overline{R}} \right) \widehat{W}_{t+1} \right) \quad (80)$$

$$\overline{Y} (\widehat{A}_t + \alpha \widehat{W}_t) = \gamma \overline{C} \widehat{C}_t + (1 - \gamma^2) \overline{C} \eta \widehat{E}_t + \overline{W} (\widehat{W}_{t+1} - (1 - \delta) \widehat{W}_t) \quad (81)$$

$$\begin{aligned} \widehat{W}_{t+1} = & -\frac{\overline{C}}{\overline{W}} \widehat{C}_t + (1 - \alpha) \frac{\overline{Y}}{\overline{W}} (\widehat{A}_t + \alpha \widehat{W}_t) + \frac{1}{\beta} \widehat{W}_t \\ & + \frac{1}{\beta} (\widehat{R}^*_t + \widehat{E}_t - \widehat{E}_{t-1}) + \widehat{\phi}_t \end{aligned} \quad (82)$$

where $\widehat{\phi} = \frac{\overline{H^H}}{\beta \overline{W}} \widehat{R}_{Xt}$ is treated as an iid zero-mean shock for the time being. This can be done because $\frac{\overline{H^H}}{\beta \overline{W}}$ affects the first-order behaviour of the model in a simple way. Specifically, $\frac{\overline{H^H}}{\beta \overline{W}}$ does not affect the eigenvalues of the first-order system. See Devereux and Sutherland (2011).

The aim is to solve the system (80) to (82) for the state space solution that expresses the three endogenous variables $\{\widehat{W}_{t+1}, \widehat{E}_t, \widehat{C}_t\}$ as a function of the five state variables $\{\widehat{W}_t, \widehat{E}_{t-1}, \widehat{A}_t, \widehat{R}^*_t, \widehat{\phi}_t\}$.

$$\begin{bmatrix} \widehat{W}_{t+1} \\ \widehat{E}_t \\ \widehat{C}_t \end{bmatrix} = \begin{bmatrix} \mathbf{W}_1 & \mathbf{W}_2 & \mathbf{W}_3 & \mathbf{W}_4 & \mathbf{W}_5 \\ \mathbf{E}_1 & \mathbf{E}_2 & \mathbf{E}_3 & \mathbf{E}_4 & \mathbf{E}_5 \\ \mathbf{C}_1 & \mathbf{C}_2 & \mathbf{C}_3 & \mathbf{C}_4 & \mathbf{C}_5 \end{bmatrix} \begin{bmatrix} \widehat{W}_t \\ \widehat{E}_{t-1} \\ \widehat{A}_t \\ \widehat{R}^*_t \\ \widehat{\phi}_t \end{bmatrix}$$

where $\mathbf{W}_1, \mathbf{W}_2, \dots$ etc. are constants to be found. We solve for this using the method of

undetermined coefficients.

The final step is to read off the relevant rows in the state space solution above to find the following expressions

$$\widehat{R}_{Xt+1} = R_1 \widehat{\phi}_{t+1} + R_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{t+1}^* \end{bmatrix} \quad (83)$$

$$\widehat{C}_{t+1} = D_1 \widehat{\phi}_{t+1} + D_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{t+1}^* \end{bmatrix} + D_3 \begin{bmatrix} \widehat{W}_{t+1} \\ \widehat{E}_t \end{bmatrix} \quad (84)$$

Recalling that $\widehat{\phi} = \frac{\overline{H^H}}{\beta \overline{W}} \widehat{R}_{Xt}$, we can rearrange equations (83) and (84) as:

$$\widehat{R}_{Xt+1} = \frac{R_2}{1 - R_1 \frac{\overline{H^H}}{\beta \overline{W}}} \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{t+1}^* \end{bmatrix} \quad (85)$$

$$\widehat{C}_{t+1} = \left(D_1 \frac{R_2}{1 - R_1 \frac{\overline{H^H}}{\beta \overline{W}}} + D_2 \right) \frac{\overline{H^H}}{\beta \overline{W}} \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{t+1}^* \end{bmatrix} + D_3 \begin{bmatrix} \widehat{W}_{t+1} \\ \widehat{E}_t \end{bmatrix} \quad (86)$$

We can then substitute the expressions in equations (85) and (86) into the portfolio balance equation (30). This gives the expression

$$\frac{\overline{H^H}}{\beta \overline{W}} = \left[R_2 \Sigma D_2' R_1' - D_1 R_2 \Sigma R_2' \right]^{-1} R_2 \Sigma D_2' \quad (87)$$

where $\Sigma = \begin{bmatrix} \sigma^2 & 0 \\ 0 & \sigma^{*2} \end{bmatrix}$.

Note that $\widehat{R}_{Xt+1}$ does not depend on any predetermined variables and is a function of

the exogenous shocks only. Recall that, by definition

$$\begin{aligned}\widehat{R}_{Xt+1} &= \widehat{R}_{t+1} - \widehat{R}_{t+1}^* - \widehat{E}_{t+1} - \widehat{E}_t \\ &= \widehat{A}_{t+1} - (1 - \alpha) \widehat{W}_{t+1} - \widehat{R}_{t+1}^* - \widehat{E}_{t+1} - \widehat{E}_t\end{aligned}$$

Recall also that up to a first-order approximation, the excess return on home assets is zero in expectation (recall that Devereux and Sutherland temporarily treats $\widehat{\phi}_{t+1}$ as a mean-zero iid shock). Using the expression above this implies that

$$\begin{aligned}\mathcal{E}_t(\widehat{R}_{Xt+1}) &= \mathcal{E}_t(-(1 - \alpha) \widehat{W}_{t+1} - \widehat{E}_{t+1} + \widehat{E}_t) \\ &= 0 \\ \therefore (1 - \alpha) \widehat{W}_{t+1} &= -\mathcal{E}_t(\widehat{E}_{t+1} - \widehat{E}_t)\end{aligned}$$

Substituting this back into the definition for $\widehat{R}_{Xt+1}$ gives

$$\widehat{R}_{Xt+1} = \widehat{A}_{t+1} - \widehat{R}_{t+1}^* - \widehat{E}_{t+1} + \mathcal{E}_t(\widehat{E}_{t+1})$$

This implies that $\widehat{R}_{Xt+1}$ is independent of predetermined variables and depends only on the exogenous shocks and the unexpected movements in the exchange rate.

3 Deriving the log-linearised model in Section 3

The derivation of the condensed log-linearised model in section 3 ((55)-(63)) is similar to the derivation of the condensed model in section 2 ((20)-(27)). Equations (55)-(59), (61)-(63) are direct log-linearisations of, respectively, equations (38), (31), (33), (34), (35), (49), (50), and (46). The remaining equation (60) is identical to (25) in section 2

and is derived using exactly the same method as described in Appendix 1.

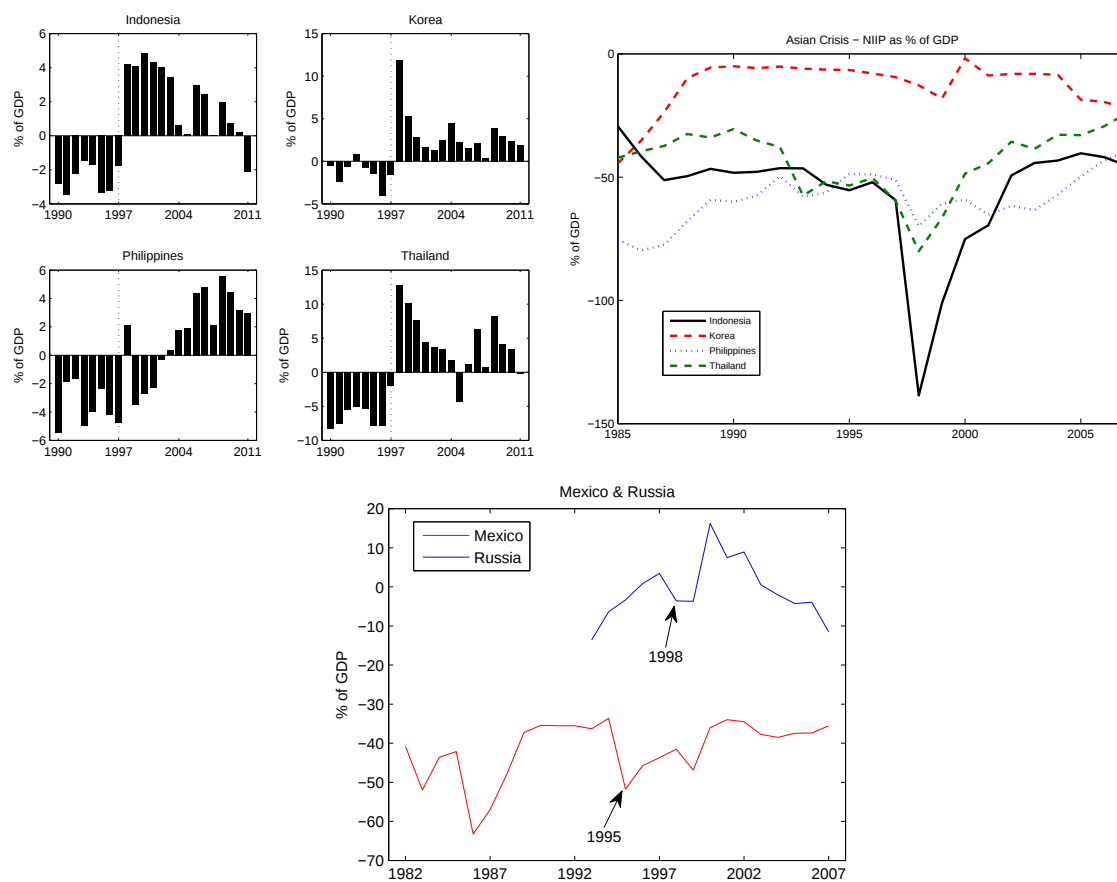
4 Historical episodes of changes in national wealth

In this Appendix, we look at whether historical episodes of large changes in national wealth roughly conform to the exchange rate predictions of this model. We can consider balance of payments crises as times in which the home country must accumulate wealth. To be clear: our model is not about balance of payments crises. Our model and balance of payments crises share just one feature: they involve twin adjustments in current accounts and exchange rates. We use episodes of balance of payments crises to provide a rudimentary picture of how the exchange rate behaves during a time when a country accumulates substantial net foreign assets. We hesitate to draw any strong conclusions because we do not employ any formal econometric techniques. We can only tentatively say that, on inspection, the evidence provides some indication that the narrative implied by the model is reasonably plausible.

A very stylised account of a balance of payments crisis is as follows. A country runs a persistent current account deficit, which is funded by foreign capital. In the event of a sudden stop in these inflows, the country must fund itself internally, which requires running up a current account surplus and accumulating net foreign assets.

Consider, for instance, the Asian Crisis. The conventional narrative of the Asian Crisis (e.g. Chang and Velasco, 1998; Corsetti, Pesenti, and Roubini, 1999; Corbett and Vines 1999; Burnside, Eichenbaum, and Rebelo 2008) is as follows. Consider table 4 (at end of the Appendix). As panel A shows, the vast majority ($\sim 94\%$) of external debt in the Asian Crisis countries was denominated in a foreign currency. Second, as panel B shows, short-term debt (with an original maturity of up to one year) made up a significant and

Figure 11: External debt flows (bars) and stocks (lines) in balance of payments crises



Source: Lane and Miles-Ferretti (2007)

growing proportion of this stock of external debt. This would imply that a large part of the external debt would need to be rolled over on a regular basis. Panel C shows that debt service and short term debt mostly exceeded the foreign reserves available to these countries. Finally, panel D shows that the main channel of intermediation of this foreign credit was via domestic banks.

This made the Asian economies vulnerable. These countries rely on rolling over a large amount of foreign-denominated debt. When foreign creditors refuse to roll over debt, these countries then lack the foreign reserves to meet these obligations. And because so much of the foreign credit was intermediated via domestic banks, any loss of confidence in their solvency would trigger a crisis. By 1996, it did appear that this loss of confidence was about to occur. Non-performing loans as a proportion of total lending had reached 8% (Korea), 13% (Indonesia), 10% (Malaysia), 14% (Philippines), and 13% (Thailand)¹⁸. Capital inflows fell and hence a sudden stop occurred.

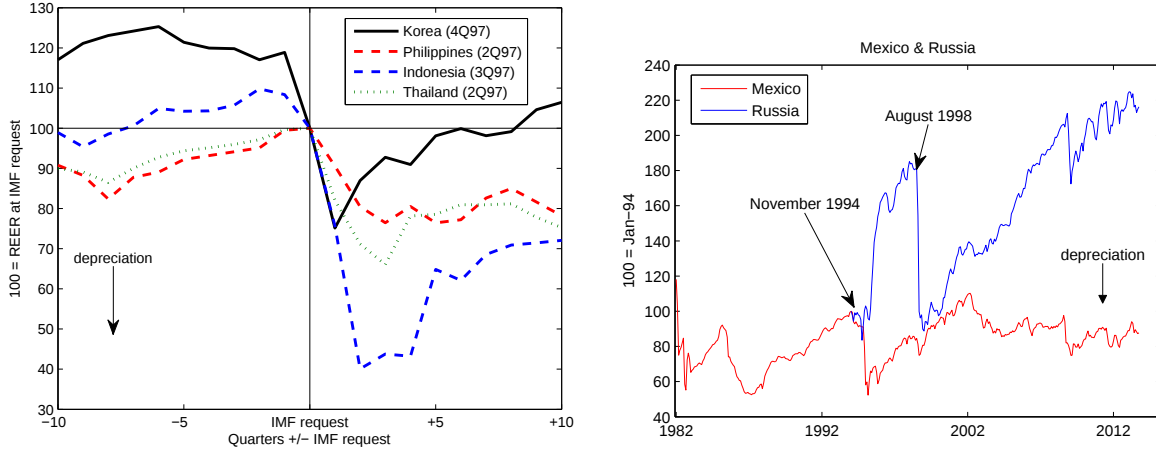
Thus affected countries needed to accumulate wealth. As figure 11 shows, this is indeed what occurred after the 1997 crisis in Asia as countries swung into current account surplus in order to improve their net international investment positions. Similarly in the Russian¹⁹ and Mexican crises in 1998 and 1994, respectively, net foreign debt reached a peak at the onset of the crisis and then gradually decumulated in the following years.

The exchange rate behaviour that is consistent with these changes in NIIPs is shown in figure 12. In all cases, the exchange rate experiences a very large and rapid fall before gradually appreciating. This thus allows these countries to swing their current account

¹⁸The corresponding numbers are 8.2% for Chile in 1982 and 12% in Mexico in 1995, the year these countries experienced debt crises.

¹⁹The Russian experience does not fit completely with the other countries because the absolute level of Russian foreign debt was reasonably small at around 4% of GDP in 1998. Some of this may be accounted for by the fact that the Russian economy had only begun to liberalise in the decade beforehand and inward foreign capital was slow to accumulate. Nonetheless, this points to the Russian crisis being one about illiquidity rather than insolvency, although the implications for the exchange rate are similar.

Figure 12: Real exchange rate behaviour during balance of payments crises



positions into surplus, and then also to reap the return on higher revaluations of home investment income as the exchange rate strengthens in subsequent periods.

Hence the prediction of exchange rate behaviour in our model is reasonably plausible. In the simulation in figure 8, which illustrates an economy that is accumulating wealth, the exchange rate initially depreciates and overshoots its long-run level, before appreciating. Conversely, an exchange rate that behaved in the opposite manner to that shown in figure 12 would be consistent with an economy that was decumulating wealth, which is shown in the simulation in figure 6. Of course, many other phenomena were occurring at the same time in 1997 (e.g. government guarantees of bank balance sheets, fixed exchange rate regimes, terms of trade shocks) and so, once again, we cannot say that this episode conclusively supports our story.

5 Extension — endogenous discount factor

In this Appendix, we show that adding an endogenous discount factor to the model in section 3 does not affect the results significantly. This means we can directly compare

the model of this Chapter with the model of Chapter 1. We proceed in the same way as in section 3.1 of Chapter 1. Suppose expected utility takes the form

$$U_t = \mathcal{E}_t \sum_{i=t}^{\infty} (\rho_i \log(C_i)) \quad (88)$$

where $\rho_0 = 1$ and $\rho_{t+1} = \rho_t \beta(C_t)$ for $t \geq 0$. The variable β has the functional form

$$\beta_t = (1 + \log(C_t))^{-\pi} \quad (89)$$

It can be shown that $\frac{d\beta}{dC} < 0$ such that as current levels of consumption increase, the household becomes more impatient. The budget constraint remains unchanged from equation (37) in section 3

$$\frac{C_t}{E_t} + W_{t+1} = (1 - \alpha) \frac{Y_t}{E_t} + \theta_{t-1} W_t R_t \frac{E_{t-1}}{E_t} + (1 - \theta_{t-1}) W_t R_t^* \quad (90)$$

The household's optimisation programme is to maximise expected utility (88) subject to the budget constraint (90) and the definition of the discount factor (89). This implies a Lagrangian of the form

$$\begin{aligned} \mathcal{L}_t = & \mathcal{E}_t \sum_{i=t}^{\infty} \rho_i \left\{ \log(C_i) - \nu_i \left(C_i + B_{H i} + \frac{B_{F i}}{E_i} - R_i B_{H i-1} - R_i^* B_{F i-1} \frac{E_i}{E_{i-1}} \right) \right\} \\ & - \sigma_i (\beta(C_i) \rho_i - \rho_{i+1}) \end{aligned}$$

where ν and σ are the Lagrange multipliers. This yields three first-order conditions

$$\begin{aligned} /W : \rho_t \nu_t &= \mathcal{E}_t \left(\rho_{t+1} \nu_{t+1} \left(\theta_t R_{t+1} + (1 - \theta_t) R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \right) \\ \nu_t &= \mathcal{E}_t \left(\nu_{t+1} \left(\theta_t R_{t+1} + (1 - \theta_t) R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \right) (1 + \log(C_t))^{-\pi} \end{aligned} \quad (91)$$

$$/C : 1 = C_t \nu_t - \frac{\pi \sigma_t}{(1 + \log(C_t))^{1+\pi}} \quad (92)$$

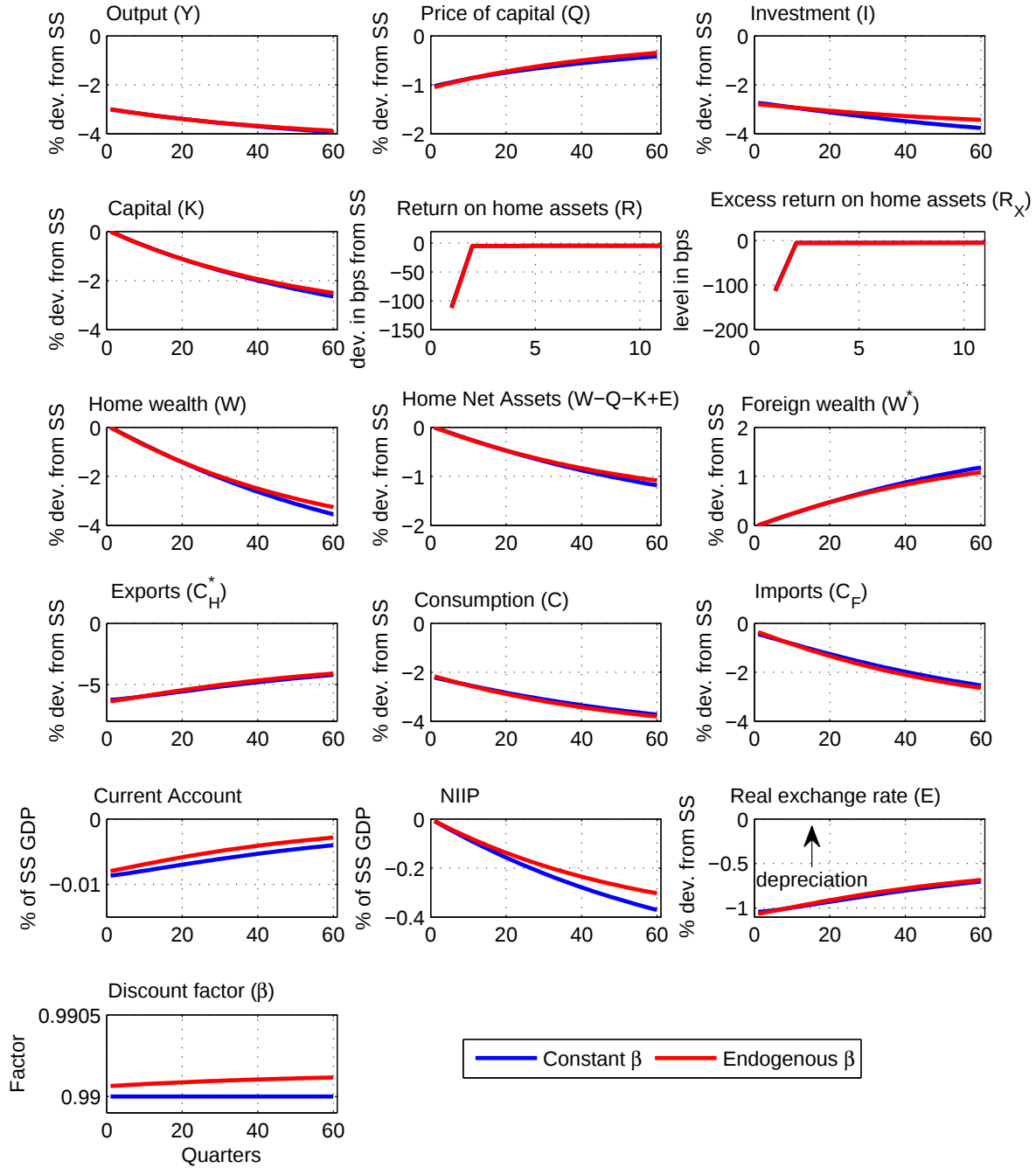
$$/\theta : \sigma_t = \mathcal{E}_t \left(\sigma_{t+1} (1 + \log(C_{t+1}))^{-\pi} \right) - \mathcal{E}_t (\log(C_{t+1})) \quad (93)$$

(91)-(93) replace the original Euler equation (38) in section 3.

Simulations of the same 3% permanent negative productivity shock are presented in figure 13. The red lines represent the model with the endogenous discount factor. The blue lines represent the old model with constant β (figure 6). As discussed in section 4.2, adding the endogenous discount factor does not significantly affect the quantitative results of this Chapter significantly and the qualitative results are identical. Indeed, Schmitt-Grohe and Uribe (2003) note that inducing stationarity through the endogenous discount factor does not alter dynamics significantly.

The reason for this is that, because wealth is pinned down by capital stocks in this Chapter, steady state consumption is uniquely pinned down and so the model is stationary even with a constant discount factor. Hence adding the endogenous discount factor does not affect model dynamics significantly.

Figure 13: Adding an endogenous discount factor



6 Extension — the special case of foreign asset bias

Given the machinery developed in this Chapter to examine home bias, it is straightforward to see what would occur in the very special case of foreign asset bias. While this may have less relevance for analysing real economies, it nonetheless is an interesting experiment. We consider the case where the parameter values representing portfolio bias are reversed so that $\theta = 0.25, \theta^* = 0.75$ which implies that households allocate one-quarter of wealth domestically.

Consider figure 14. Again, there is little to note about the first six panels. In this case, as in the case where agents exhibit home portfolio bias, capital needs to decumulate following the shock because each unit of capital is now less productive than before. The supply of home assets declines. The responses of these variables are quantitatively similar to the case of home asset bias. This is because changing the structure of asset ownership and portfolio bias does not affect the path of capital, which is driven by the exogenous change in productivity.

Unlike in the case with home bias, however, because home investors exhibit a bias in favour of foreign assets, and foreign agents exhibit a bias in favour of home assets, then, in order to divert world asset demand towards foreign assets, foreign wealth must fall, while home wealth must rise at the new steady state. This is illustrated in the middle three panels of figure 14.

This rise in home wealth and fall in foreign wealth is achieved by the home country running a current account surplus. So, in the second-last row of figure 14, we see that, in this case, exports rise, and consumption and home imports fall. This results in a small but persistent current account surplus that leads to the accumulation of home net wealth.

The implications for the real exchange rate are thus the opposite to what they were under home asset bias. In order to induce a current account surplus, the exchange rate must remain undervalued and more depreciated (above) relative to its long-run value. This is why the exchange rate (bottom right in figure 14) initially depreciates, before gradually appreciating to this long-run value. The gradual appreciation of the exchange rate along the adjustment path improves the terms of trade of the home country, which contributes to the accumulation of home stock of wealth.

The effect of varying the value of θ^* in the special case of foreign bias

From figure 14, it is evident that a lower value of θ^* augments the magnitude of the response of the exchange rate to the shock. It is straightforward to interpret this result. A decrease in the proportion of the foreign portfolio allocated to the home asset θ^* is equivalent to a decrease in the world *ex ante* preference for the home asset. So, when the return on the home asset falls, world investors must be compensated even more than previously so as to ensure there is no arbitrage in asset markets. The exchange rate must experience a greater appreciation along the adjustment path, which thus means that the initial depreciation must be greater.

Furthermore, using equation (51) and (53), we can express the ratio of the new steady state value of home wealth to the old value $\frac{\widetilde{W}}{\overline{W}}$ as

$$\frac{\widetilde{W}}{\overline{W}} = \frac{\theta^* \Lambda - \phi (1 - \theta^*)}{\theta^* \Lambda - (1 - \theta^*)}$$

It can be shown²⁰ that as θ^* decreases, $\frac{\widetilde{W}}{\overline{W}}$ rises and so the required increase in home wealth after the shock is greater. As equation (65) implies, a greater rise in home wealth

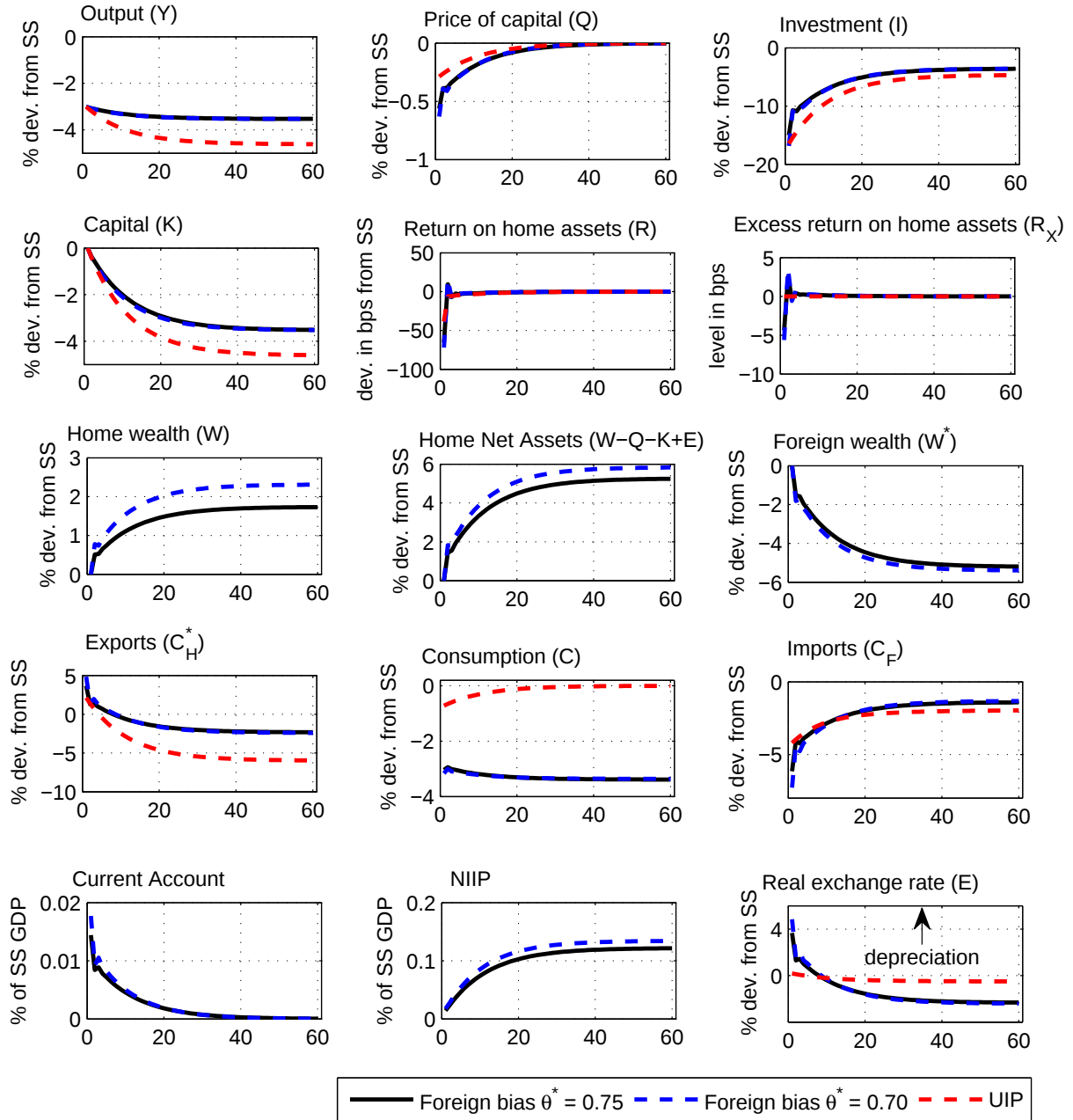
²⁰ $\frac{d\left(\frac{\widetilde{W}}{\overline{W}}\right)}{d\theta^*} = -\frac{\Lambda(1-\phi)}{(\theta^* \Lambda - (1 - \theta^*))^2} < 0$

thus requires larger valuation effects and larger trade balances. Hence, as expected, the lower the value of θ^* , the more the exchange rate initially depreciates. Distorting asset substitutability even more increases the size of the initial depreciation.

This allows us to interpret the effect on the other variables. Because a lower θ^* requires a larger accumulation of home net wealth, exports rise by more, and imports and home consumption fall by more. The home capital stock (representing home liabilities) must decumulate by more and so the price of capital falls by more to induce a greater drop in investment. This feeds into the rate of return on home assets since a larger fall in the price of capital leads to a larger initial decline in R but a faster recovery because capital is decumulating faster under a lower value of θ^* .

Note that, with the exception of the wealth stock variables $(W, W^*, N, NIIP)$, changing the value of θ^* does not affect the new steady state long-run levels. This is because the new steady state of these variables is pinned down by the exogenous productivity shock and is unaffected by conditions in asset markets.

Figure 14: Foreign bias: permanent fall in productivity



7 Extension — a two-country model

In this Appendix, we consider a symmetric two-country model in which each country is identical to the home country in our main model (section 3). The aim of this Appendix is to show that our results are robust to generalising the model to a two-country one. The model equations (linearised) consist of the following system for countries $j \in \{A, B\}$

$$\mathcal{E}_t(\widehat{C}_{At} - \widehat{C}_{At+1}) = \mathcal{E}_t(\bar{\theta}\widehat{R}_{At+1} + (1 - \bar{\theta})(\widehat{R}_{Bt+1} + \widehat{E}_{t+1} - \widehat{E}_t)) \quad (94)$$

$$\mathcal{E}_t(\widehat{C}_{Bt} - \widehat{C}_{Bt+1}) = \mathcal{E}_t(\bar{\theta}\widehat{R}_{Bt+1} + (1 - \bar{\theta})(\widehat{R}_{At+1} - \widehat{E}_{t+1} + \widehat{E}_t)) \quad (95)$$

$$\widehat{Y}_{jt} = \widehat{A}_{jt} + \alpha\widehat{K}_{jt} \quad (96)$$

$$\widehat{R}_{jt} = -\widehat{Q}_{j,t-1} + \frac{(1 - \delta)}{\bar{R}}\widehat{Q}_{jt} + \left(1 - \frac{1 - \delta}{\bar{R}}\right)(\widehat{Y}_{jt} - \widehat{K}_{jt}) \quad (97)$$

$$\widehat{K}_{j,t+1} = (1 - \delta)\widehat{K}_{jt} + \delta\widehat{I}_{jt} \quad (98)$$

$$\widehat{Q}_{jt} = \xi(\widehat{K}_{j,t+1} - \widehat{K}_{jt}) \quad (99)$$

$$\bar{Y}\widehat{Y}_{jt} = \gamma\bar{C}\widehat{C}_{Hjt} + (1 - \gamma)\bar{C}\widehat{C}_{F\bar{j}t} + \bar{I}\widehat{I}_{jt} \quad (100)$$

$$\widehat{C}_{Hjt} = \widehat{C}_{jt} - \eta(\widehat{P}_{Hjt} - \widehat{P}_{jt}) \quad (101)$$

$$\widehat{C}_{Fjt} = \widehat{C}_{jt} - \eta(\widehat{P}_{Fjt} - \widehat{P}_{jt}) \quad (102)$$

$$\widehat{P}_{jt} = \gamma\widehat{P}_{Hjt} + (1 - \gamma)\widehat{P}_{Fjt} \quad (103)$$

$$\widehat{P}_{HA_t} = 0 \quad (104)$$

$$\widehat{P}_{FA_t} = \widehat{E}_t + \widehat{P}_{HB_t} \quad (105)$$

$$\begin{aligned} \bar{K}(\widehat{Q}_{At} + \widehat{K}_{At+1} - \widehat{E}_t) &= \bar{\theta}\bar{W}\widehat{W}_{At+1} + (1 - \bar{\theta})\bar{W}\widehat{W}_{Bt+1} \\ &\quad + 2\zeta(\widehat{R}_{At+1} - \widehat{R}_{Bt+1} - \widehat{E}_{t+1} - \widehat{E}_t) \end{aligned} \quad (106)$$

$$\begin{aligned} \bar{K}(\widehat{Q}_{Bt} + \widehat{K}_{Bt+1}) &= (1 - \theta)\bar{W}\widehat{W}_{At+1} + (1 - \bar{\theta})\bar{W}\widehat{W}_{Bt+1} \\ &\quad - 2\zeta(\widehat{R}_{At+1} - \widehat{R}_{Bt+1} - \widehat{E}_{t+1} - \widehat{E}_t) \end{aligned} \quad (107)$$

$$\begin{aligned} \widehat{W}_{At+1} &= \frac{\bar{C}}{\bar{W}}(\widehat{E}_t - \widehat{C}_{At}) + (1 - \alpha)\frac{\bar{Y}}{\bar{W}}(\widehat{Y}_{At} - \widehat{E}_t) \\ &\quad + \bar{R}\widehat{W}_{At} + \bar{\theta}\bar{R}(\widehat{R}_{At} - \widehat{E}_t + \widehat{E}_{t-1}) + (1 - \bar{\theta})\bar{R}\widehat{R}_{Bt} \end{aligned} \quad (108)$$

Our baseline simulation of a permanent 3% fall in home productivity is presented in figure 15. The behaviour of each home country variable (blue lines) is identical to that in the main model of this Chapter and can be interpreted in the same way (see section 4.2). The behaviour of foreign country variables (red lines) can be interpreted straightforwardly. The home productivity shock causes demand for foreign-produced goods to decline. Hence the foreign price of capital, investment, output, and asset return edge lower. As required by the asset equilibrium conditions in the presence of home bias, foreign wealth rises at the new steady state. This is achieved by a fall in foreign aggregate consumption which gives rise to a current account surplus for the foreign country.

The exchange rate behaves in the same way as in section 4.2. The home (foreign) country runs a deficit (surplus) and so the home exchange rate over-appreciates and overshoots, hence becoming over-valued (relative to its long-run value), which gives rise to the necessary trade balances for home and foreign countries.

Figure 15: Two country model - Permanent fall in productivity

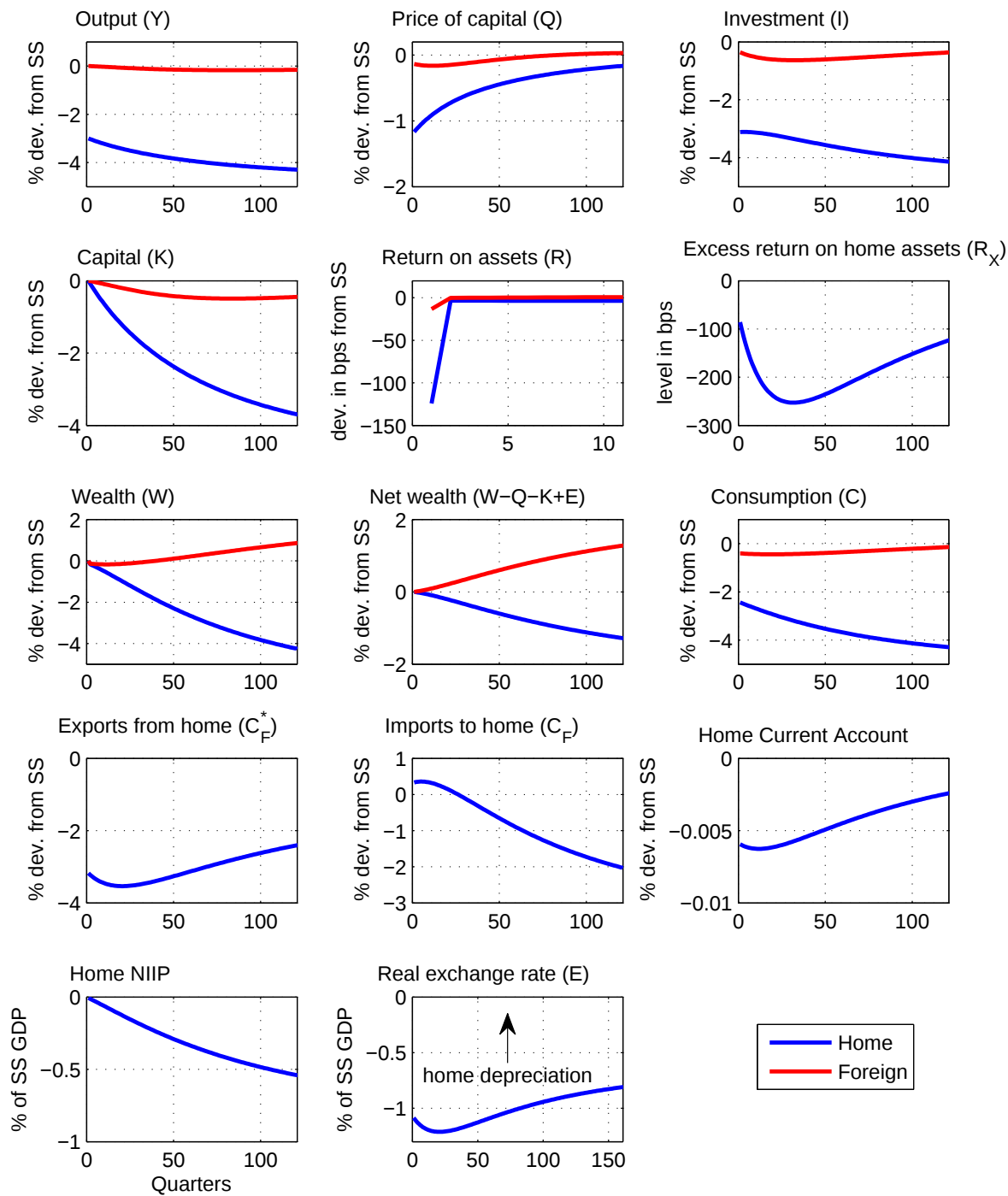


Table 4: Stylised facts about external debt prior to the Asian Crisis

A. Local currency as % of external debt

	Jun-90	Jun-94	Jun-97
Indonesia	2.33	2.73	2.15
Korea	11.49	6.61	5.95
Malaysia	3.09	10.91	10.33
Philippines	4.75	5.39	15.86
Thailand	5.82	5.87	5.63
Total	6.30	5.91	6.02

Source: BIS and Chang & Velasco (1998)

B. Short-term debt as % of external debt

	1990	1991	1992	1993	1994	1995	1996
Korea	30.87	28.19	26.99	25.85	25.47	51.60	50.20
Indonesia	15.92	18.00	20.52	20.17	18.05	20.87	24.98
Malaysia	12.43	12.14	18.18	26.58	21.13	21.19	27.83
Philippines	14.48	15.24	15.93	14.01	14.29	13.38	19.34
Singapore	17.51	18.92	19.91	17.87	13.28	14.56	19.81
Thailand	29.63	33.13	35.22	53.01	60.67	72.36	41.41
HK	45.97	46.63	45.89	41.19	30.04	28.36	43.57
China	16.85	17.89	19.01	17.80	17.40	18.91	19.72
Taiwan	88.31	86.49	86.93	84.99	76.75	72.18	68.44

Source: World Bank

C. Debt service plus short-term external debt as % of foreign reserves

	1990	1991	1992	1993	1994	1995	1996
Korea	127.43	125.90	110.35	105.66	84.90	204.93	243.31
Indonesia	282.92	278.75	292.03	284.79	277.95	309.18	294.17
Malaysia	63.96	45.87	45.55	42.37	48.73	55.92	69.33
Philippines	867.64	256.99	217.08	212.60	171.98	166.60	137.06
Thailand	102.35	99.34	101.34	120.28	126.54	138.13	122.62
HK	30.51	26.87	22.82	20.64	22.02	16.82	-
China	55.34	43.70	108.55	113.74	54.08	49.61	38.46
Taiwan	23.92	22.29	23.08	25.21	23.69	24.20	-

Source: World Bank

D. The role of banks in intermediating foreign credit (1996)

	Indonesia	Korea	Malaysia	Philippines	Thailand
Domestic bank lending to private sector (% GDP)	55	62	93	49	102
Domestic bank borrowing from intl banks (% of domestic lending)	18	30	17	21	44

Source: World Bank, IMF, BIS

Chapter 3: Financial frictions, risk premia, and exchange rate volatility*

Simon Wan^{†‡}

Abstract

This Chapter examines the effect of financial frictions on exchange rate volatility. There are three key findings. First, financial frictions increase exchange rate volatility. This is because financial frictions give rise to risk premia that further widen after negative shocks, which raises the burden of adjustment on the exchange rate. Second, contrary to the currency crisis literature, large currency mismatches are not necessary for financial shocks to generate volatile jumps in the exchange rate. This is because spikes in risk premia can occur regardless of the composition of balance sheets. Finally, financial shocks have a greater effect on exchange rates than similarly-sized productivity shocks because they give rise to larger increases in risk premia.

We build a model of a small open economy with a banking sector that borrows from depositors, subject to a financial friction. The main channel of transmission from the financial shock to the exchange rate is the risk premium. If a financial shock worsens bank leverage, creditors compensate for this by raising the risk premium, in effect demanding that banks earn a higher return on their assets above the rate at which creditors could save risklessly. Because the world riskless rate does not fall and the bank's earnings on risky assets do not rise, it is the exchange rate that must bear the burden of adjustment by appreciating along the adjustment path. A large cumulative appreciation along the adjustment path implies a sharp initial depreciation of the exchange rate (recall Chapter 1). In effect, creditors withdraw from home banks, leading to financial outflows that cause the exchange rate to fall initially. Financial outflows continue until the exchange rate has depreciated to the point where it is so under-valued that the subsequent per-period appreciation is sufficient to keep creditors satisfied with funding home banks.

JEL classification: F310, G010

Keywords: exchange rate volatility, financial frictions, 2008 financial crisis

*A paper based on this Chapter with the title “Understanding exchange rate movements during the 2008 financial crisis” is currently undergoing revision and resubmission.

[†]Department of Economics, University of Oxford

[‡]simon.wan@economics.ox.ac.uk

Contents

1	Introduction	173
1.1	Related literature	176
1.2	Structure of the Chapter	180
2	The financial sector	181
2.1	Bank balance sheet	181
2.2	The friction - loan contracts between banks and depositors	183
2.3	The optimal contract — choosing $\bar{\omega}_i$ and F_i	184
2.4	Partial equilibrium in the banking sector	188
2.5	Evolution of aggregate bank net worth	190
2.6	Foreign debt and balance sheet effects	192
3	Non-financial sector	193
3.1	Households	194
3.2	Consumption	196
3.3	Firm	197
3.4	Capital goods producer	199
3.5	General equilibrium conditions	199
4	Response to a financial crisis	201
4.1	Parameterisation	201
4.2	Revisiting the banking sector partial equilibrium	204
4.3	Simulation of a bank net worth shock	208
4.4	Effect of the currency mismatch	213
4.5	Comparison with a technology shock	215
4.6	Comparison with a model without financial frictions	217

5	Discussion	230
5.1	Summary of results	230
5.2	Other types of financial frictions	232
5.3	The 2008 crisis in perspective	234
6	Concluding remarks	237
	Appendix	244
1	The log-linearised model	244
2	The optimal steady state bank portfolio	246
2.1	Preliminaries	246
2.2	The optimal steady state bank portfolio	249
2.3	Details — Finding the functional forms of $\chi(\bar{\omega}), \chi(\bar{\omega}^*)$	252
2.4	Details — Deriving the second order arbitrage equation	254
2.5	Details — Deriving the expression for excess returns	256
3	Two-period model using moral hazard friction	257
3.1	Model	258
3.2	Equilibrium in the two-period model	261
3.3	Response to a financial crisis	264

1 Introduction

This Chapter extends the analysis of Chapter 1 in order to investigate the effect of financial frictions on exchange rate volatility. The model here is the Chapter 1 model with UIP, with the addition of a banking sector and financial frictions. There is a well-developed literature on financial frictions and on incorporating financial frictions into open economy models. This Chapter manipulates a model of an open economy with financial frictions in order to give an explicit treatment of the interaction between financial frictions and exchange rates. In doing so, we provide an account of sharp exchange rate depreciations that is a modest innovation to the old currency crisis literature.

This Chapter makes three findings. First, financial frictions do increase the volatility of the exchange rate. The reason for this is straightforward. In the presence of financial frictions, there exists a risk premium, a positive spread between the return on risky assets and the riskless rate. Following a negative shock, this spread will typically widen. And it is because of this increase in the risk premium that means that the burden of adjustment on the exchange rate is greater following a shock. Using the analysis of Chapter 1, we know that if the required out-of-steady-state adjustment of the exchange rate increases, then the size of the initial jump tends to increase as well.

I explain this result in greater detail when I provide an overview of the model below but, for now, we can interpret this result very simply. Consider a UIP condition with the difference between home and foreign interest rates on the left hand side of the equation and the expected change of the exchange rate on the right hand side. Suppose we augment the interest-rate differential on the left hand side with a country-specific risk premium. Then, by definition, the required adjustment of the exchange rate is also greater, compared to the case where there is no risk premium. And, given the same

long run level of the exchange rate, a greater out-of-steady-state adjustment typically translates into larger initial jumps after shocks.

The second finding of this Chapter relates to the currency mismatch of banks. The Asian Crisis literature (e.g. Krugman, 1999; Cespedes, Chang and Velasco, 2004) stressed the idea that banks or firms may have mismatches on their balance sheets by holding home-denominated assets and foreign-denominated debt. This mismatch is an underlying reason as to why large falls in exchange rates can occur in these old currency crisis models. This Chapter finds that the currency mismatch can have important effects. However, this Chapter also shows that financial shocks can lead to large falls in the exchange rate for reasons other than the mismatch. This is because, in the presence of financial frictions, spikes in risk premia can occur after negative shocks regardless of the composition of the balance sheet. This is important because the mismatch in balance sheets is typically small, especially in advanced economies (see panels C and D of table 2).

Given this setup, it is then natural to compare the effect of financial shocks on the exchange rate with that of productivity shocks. The third finding of this Chapter is that financial shocks (in our model, a shock to bank net worth) have a larger effect on exchange rates than aggregate productivity shocks, conditional on the shocks having similar-sized effects on other important variables (we perform a sensitivity analysis to ensure that this result is robust to this particular calibration). This is for the same reason as above. Financial shocks lead to larger spikes in the risk premium compared with productivity shocks, and hence have a larger effect on exchange rates.

I now elaborate on the findings above by giving a stylised summary of how the model in this Chapter works. Banks obtain funding from depositors in order to fund purchases of risky assets. The financial friction resides in the loan contracts between banks and

depositors. We simulate an exogenous fall in bank net worth. Bank leverage positions worsen. Depositors thus demand a higher risk premium for supplying credit to a more highly-leveraged banking sector. This means that banks are required to earn a higher return on their portfolios above the rate at which depositors can save risklessly at home and abroad. Suppose that after the shock the return on bank assets also falls but the world riskless rate remains constant. Then, the only way the home bank can earn the required spread on its portfolio above the world riskless rate is if the exchange rate adjusts.

The exchange rate achieves this by appreciating along the adjustment path. This raises the value of bank earnings relative to the rate at which depositors could save overseas, thus allowing the bank to earn the required spread above the world riskless rate. If this cumulative per-period appreciation of the exchange rate is sufficiently large, then (recall Chapter 1) the exchange rate must initially depreciate sharply in order to accommodate this subsequent adjustment. What is happening is that depositors, upon observing the deterioration in bank leverage, withdraw funding from banks and flood to riskless assets abroad, which triggers financial outflows and causes the exchange rate to depreciate. This occurs until the point at which the exchange rate is sufficiently under-valued. This is where the subsequent per-period appreciation raises bank earnings relative to the foreign riskless rate by the necessary amount to keep creditors satisfied with funding home banks.

Essentially this is a story about spreads. In order to satisfy creditors after the negative shock, the bank must earn a higher spread on its portfolio above the home and foreign riskless rates. And since (by construction) the foreign riskless rate does not move, the exchange rate must also bear the burden of adjustment. The crucial factor is that depositors have access to both home and foreign riskless assets and so the home banking

sector must earn higher returns relative to both of these riskless rates¹.

1.1 Related literature

This Chapter is broadly related to three strands of existing literature.

First, because we are exploring the idea of a financial shock leading to large falls in exchange rates, it is natural to look to the third-generation currency crisis literature that also examines this issue. This literature is mainly a response to the 1997 Asian Crisis. This work is exemplified by Krugman (1999), who develops a multiple equilibria model with self-fulfilling expectations. In his model, an expectation of a depreciation leads to a deterioration of the net worth of firms that have high foreign debt exposure. This then leads to capital outflows and an actual depreciation. Later additions have been variations of this theme. Cespedes, Chang and Velasco (2004) nest the intuition of Krugman (1999) in a general equilibrium model with *ad hoc* financial frictions and show that a real devaluation has a detrimental effect on firm net worth but that this may be mitigated by higher demand for exports. Aghion, Bacchetta and Banerjee (2004) explore the possibility of contractionary depreciations: for sufficiently large depreciations, the negative effect of a depreciation on home balance sheets dominates the positive effect of a rise in net exports. Sanchez (2008) uses a simple model to show that, in an economy that is vulnerable to contractionary depreciations, policy-makers raise the interest rate so much in response to a financial shock that the exchange rate actually appreciates.

Second, because we stress the risk premium as the channel of transmission between financial shocks and the exchange rate, it is natural also to look to the open macroeco-

¹This is qualitatively identical to a world in which depositors were confined to saving in their own domestic riskless asset but the home bank has to obtain funding from both home and foreign depositors.

economic literature that examines the role of risk in exchange rate determination. As early as Fama (1984) there have been suggestions that risk premia are important in exchange rates (and hence in explaining the apparent failure of the risk-neutral formulation of the uncovered interest parity condition). More recently, Li, Ghoshray and Morley (2012) found that the risk premium is empirically significant in exchange rates in most countries. Furthermore, Cappiello and De Santis (2005) find strong support for including a risk premium term into an estimation of the UIP condition with equity returns taking the place of interest rates. Risk premia are typically specified in one of two main ways. It is either an *ad hoc* term added into the UIP condition, as in Anker (1999) and McCallum (1994). Or the risk premium is derived from the second-order approximations of the expectational equations of the model, as in Obstfeld and Rogoff (1998). It is also worthwhile to take note of the recent literature (e.g. Amano and Shukayev, 2012) that emphasises the importance of shocks to the risk premium in explaining more general features in quantitative DSGE models (not just exchange rate determination).

In terms of the question addressed here and the answer we provide, this Chapter is broadly similar to the two bodies of literature cited above. We are interested in examining the link between stresses in the financial sector and rapid depreciations of the exchange rate. Our answer is that the risk premium arising from these financial shocks drives the movement of the exchange rate.

In terms of the methodology and model structure, this Chapter is broadly similar to the more recent literature on financial frictions. This is the third body of literature related to this Chapter. The financial friction we incorporate is based on the well-understood financial accelerator framework by Bernanke, Gertler and Gilchrist (1999) - hereafter BGG. This framework has been further developed more recently. Hirakata, Sudo and Ueda (2011) add a financial sector and thus a second layer of financial frictions:

consumers lend to banks; banks lend to firms. Luk and Vines (2011) adapt Hirakata *et al.* (2011) by having banks purchase state-contingent equity in firms rather than provide loans. Our model is closest to that of Luk and Vines (2011). Common features include: the formulation of the financial friction, the banking sector, and the representative household in a flexible price world. The main difference is that we nest the model in a small open economy rather than a closed one. This means that banks now hold both home and foreign assets and depositors in banks have home and foreign riskless outside options.

We use the financial accelerator framework in our model. However, we can show that the results are qualitatively identical if we use another type of financial friction. This is because financial friction models share the common property of generating a non-negative risk premium that widens following negative shocks. Because of this, another type of financial friction would yield similar results. For instance, the moral hazard friction (Gertler and Kiyotaki 2010; Gertler and Karadi 2011) implies that banks can abscond with a fraction of bank profits. Depositors at banks thus demand a risk premium on bank earnings in order to be compensated for the expectation of absconding. This risk premium is also positively related to the leverage position of the bank. Hence, a worsening of bank leverage would raise the risk premium, and thus give rise to the same effect as in this model.

This Chapter makes two main contributions to the literature cited above.

First, this Chapter bridges the gap between (i) the objectives of the currency crisis literature and the risk-premium-open-macroeconomics literature (first and second strands) and (ii) the methodology of the more recent microfounded financial frictions work (third strand). The various classes of existing currency crisis models are one-period models that typically examine comparative statics between two steady states. This means that

the dynamic adjustment of the exchange rate that we hypothesise cannot be examined in these types of models. Recall from Chapter 1 that exchange rate jumps can be followed by prolonged and gradual adjustment. This means we need to nest our analysis in a multi-period general equilibrium framework. This Chapter contributes to this body of literature by building a dynamic model that takes into account the behaviour of exchange rates out of steady state. Furthermore, by introducing the more recent financial frictions literature, we are able to model the fundamental frictions in the banking sector in a microfounded manner, thus updating the *ad hoc* specification of banking behaviour in the currency crisis models. This also means that we can model risk premia in a microfounded manner (arising from the optimising behaviour of participants in the market for loanable funds), rather than as an *ad hoc* term added into the UIP condition.

Previous studies have incorporated financial frictions into open economies. Gertler, Gilchrist and Natalucci (2007) nest a BGG friction in a small open economy in order to explain stylised facts about the South Korean economy during the Asian Crisis. Claus (2007) and (2011) performs the same exercise with the New Zealand economy. Ueda (2012) does this with a large advanced economy in North America or Western Europe. Elekdag, Justiniano and Tchakarov (2006) conduct an empirical study of the effect of financial frictions on the real non-financial economy. These papers are thus primarily concerned with exploring the business cycle properties of financial frictions in open economies and do not provide an explicit treatment of the effect of these frictions on the exchange rate. This Chapter aims to fill this modest gap in the literature.

The second contribution of this Chapter relates to the concept of the currency mismatch. The currency crisis literature (e.g. Cespedes, Chang and Velasco, 2004) focuses heavily on the currency mismatch in firms and banks. That is, the large falls in exchange rates predicted by currency crisis models tend to depend on the assumption that banks and

firms hold foreign-denominated debt but home-denominated assets. This means that a small depreciation worsens the balance sheets of home banks and firms, leading to capital outflows by foreign creditors, which then causes the exchange rate to fall further. This feedback loop leads to a large fall in exchange rates.

The issue with this is that there is evidence that large currency mismatches do not exist. Certainly, the mismatches are small in advanced economies (see panels C and D of table 2). There is evidence that mismatches are also small in emerging markets. Bleakley and Cowan (2008) find that, in Latin America, firms and banks will hedge against the risk of holding dollarised debt by holding dollarised assets or derivatives. Carranza, Sanchez and Biscarri (2011), likewise, find that only a large depreciation has empirically noteworthy effects on balance sheets and the macroeconomy. Hence, in this Chapter, the results of our model do not depend on a currency mismatch. Indeed, using the portfolio optimisation technique of Devereux and Sutherland (2011), we find that banks do hedge against denomination risk by holding home and foreign assets in roughly the same proportion as home and foreign liabilities (see Appendix 2). We find that, contrary to the currency crisis literature, large falls in exchange rates can occur after financial shocks, even in the absence of a mismatch, because increases in the risk premium can arise for reasons unrelated to the composition of the balance sheet.

1.2 Structure of the Chapter

The remainder of this Chapter is organised as follows. Section 2 develops the financial sector in the model. Section 3 develops the non-financial sector. Section 4 analyses the response of the exchange rate to financial and productivity shocks. Section 5 summarises these results and section 6 concludes.

2 The financial sector

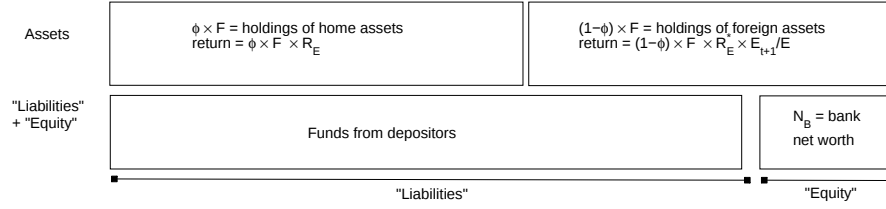
This is a model of a small open-economy with a banking sector. It is the Chapter 1 model with UIP with the addition of a banking sector and financial frictions. In the non-financial side of the economy, there is a standard goods-producing firm that hires labour from households and purchases capital goods from capital goods producers. It is in order to fund these capital purchases which means that firms have to issue assets to banks. The banking sector in turn funds these asset purchases by obtaining funding from depositors. Depositors reside at home. However, they have access to both home and foreign riskless assets. The financial friction, which resides in the loan contract between banks and depositors, is a standard BGG-type friction. We demonstrate in section 5.2 that other financial friction specifications (e.g. Gertler and Karadi, 2011) would yield similar results.

We first develop the financial sector, before moving to the non-financial side of the economy. The specification of banking behaviour follows Luk and Vines (2011), although we extend their closed economy model to the open economy. This means that banks now hold two types of assets (home and foreign) and depositors have two riskless options (home and foreign).

2.1 Bank balance sheet

In the home country, there is a continuous spectrum of banks indexed $i \in [0, 1]$. This is a standard starting point for the BGG framework. We will later show that the banking sector can be aggregated and treated as a whole but, for now, this is a necessary first step.

Figure 1: Bank balance sheet



Bank- i holds quantity F_i of assets. Proportion ϕ_i of these assets are held in real bonds in home firms that yield a gross return of R_E . The remaining fraction $1 - \phi_i$ is held in foreign assets that yield a gross return $R_E^* \frac{E_{t+1}}{E_t}$. E is the real exchange rate defined as the price of foreign goods relative to home goods - a rise in E is a depreciation for home. R_E is determined by the aggregate productivity of home firms and we treat the foreign return as exogenous $R_E^* \sim \text{iid}(\bar{R}_E, \sigma^{*2})$. The foreign asset is in zero net supply; the home asset supply is determined in general equilibrium by the home capital stock. This specification broadly follows Ueda (2012), although in his paper the fraction ϕ_i is fixed, whereas in this Chapter it is time-varying. It is assumed that bank net worth N_{Bi} is insufficient to cover these asset purchases and so the bank borrows the shortfall $F_i - N_{Bi}$ from depositors. Figure 1 summarises the bank's balance sheet. Following BGG, we assume that each bank experiences an idiosyncratic shock ω_i so that the period $t + 1$ gross revenue of bank- i is equal to

$$\omega_i \times (\text{assets} \times \text{return on assets}) \equiv \omega_i F_i \left(\phi_i R_E + (1 - \phi_i) R_E^* \frac{E_{t+1}}{E_t} \right)$$

The idiosyncratic ω shocks² are drawn independently from identical log-normal distri-

²There is no predominant way in the literature of interpreting the ω shock to banks but it is not difficult to motivate. Even though risky assets yield the same return for all banks, each bank may differ in its efficiency in intermediating funds between depositors and risky assets. This may arise because each bank may have a different ability to purchase assets efficiently (e.g. at a low bid-ask spread), given different degrees of market access across time. Furthermore, the efficiency of banks may depend on the unobservable effort of bank staff, who may also possibly abscond with bank assets. We can reasonably think of these factors as stochastically determined and the private information of individual

butions with mean one and standard error σ^ω ³.

2.2 The friction - loan contracts between banks and depositors

We now characterise the loan contracts between banks and depositors (who, unlike banks, are treated as a single aggregate entity), which is the basis of the BGG financial friction in our model. The friction arises due to asymmetric information. Banks can observe their own productivity, but depositors *ex ante* cannot and must pay a cost equal to some proportion⁴ μ of the bank's gross revenue in order to observe ω_i . Townsend (1979) found the optimal contract. It takes the following form. Banks set some threshold level $\bar{\omega}_i$ that determines the contractual no-default repayment rate

$$\begin{array}{ccc} \text{contractual} & \times & \text{amount} \\ \text{repayment rate} & & \text{borrowed} \end{array} = \bar{\omega}_i \times (\text{assets} \times \text{return on assets}) = \bar{\omega}_i F_i \left(\phi_i R_E + (1 - \phi_i) R_E^* \frac{E_{t+1}}{E_t} \right)$$

The higher the threshold $\bar{\omega}_i$, the higher the depositor's contractual share of bank income. After bank earnings and the idiosyncratic shock are realised, one of two events occur. If $\omega_i \geq \bar{\omega}_i$, banks repay this contractual rate. If $\omega_i < \bar{\omega}_i$, bank-*i* declares default and so the depositor pays the monitoring cost to observe the realised ω_i and receives all the earnings of the defaulting bank $(1 - \mu) \omega_i F_i \left(\phi_i R_E + (1 - \phi_i) R_E^* \frac{E_{t+1}}{E_t} \right)$.

Each bank-*i* signs one contract with the aggregate depositor in the home country (although this depositor has access to both home and foreign riskless assets) which specifies a threshold level $\bar{\omega}_i$. The timing of the bank's decision is as follows. At the end of period t , banks take their accumulated net worth up to that point N_{Bit} , and, together with banks.

³It can be shown that $F(\omega) = \Phi \left(\frac{\log \omega + \frac{1}{2}(\sigma^\omega)^2}{\sigma^\omega} \right)$ and $\mathcal{E}(\omega | \omega < \bar{\omega}) \equiv G(\omega) = \Phi \left(\frac{\log \bar{\omega} - \frac{1}{2}(\sigma^\omega)^2}{\sigma^\omega} \right)$ where $\Phi(\cdot)$ is the standard normal CDF

⁴An "auditing cost", as interpreted by BGG.

funding from depositors, purchase assets F_{it} . At the end of $t + 1$, these assets pay their respective return. Banks pay depositors their shares of the gross revenue as determined by $\bar{\omega}_{it+1}$. Bank net profit then determines new net worth N_{Bt+1} .

2.3 The optimal contract — choosing $\bar{\omega}_i$ and F_i

We now specify the bank's optimisation problem, which determines how the threshold $\bar{\omega}_i$ and F_i are chosen. First, we define some relevant terms. We denote the expected productivity of a defaulting bank as $G(\bar{\omega}_i) \equiv \mathcal{E}(\omega_i | \omega_i < \bar{\omega}_i) = \int_0^{\bar{\omega}_i} \omega_i dF(\omega)$. In the absence of the financial friction, we denote the depositor's share of bank- i 's per-period income as Γ_i where

$$\Gamma_i = \underbrace{G(\bar{\omega}_i)}_{\text{expected } \omega \text{ if default}} + \underbrace{(1 - F(\bar{\omega}_i))}_{\text{probability of no default}} \times \underbrace{\bar{\omega}_i}_{\text{depositor's no-default share}}$$

After we introduce the monitoring cost, the depositor's net share of bank- i revenue becomes Ψ_i

$$\Psi_i \equiv \underbrace{(1 - \mu) G(\bar{\omega}_i)}_{\substack{\text{expected } \omega \text{ if default} \\ \text{minus monitoring cost}}} + \underbrace{(1 - F(\bar{\omega}_i)) \bar{\omega}_i}_{\substack{\text{no-default} \\ \text{expected share}}} = \Gamma_i - \mu G(\bar{\omega}_i)$$

Depositors are risk-neutral and have outside options. Depositors can save risklessly in the home riskless asset for return R or in the foreign riskless asset for return $R^* \frac{E_{t+1}}{E_t}$ ⁵.

⁵These returns are riskless in that R_{t+1} and R_{t+1}^* are known at time t .

This implies that bank- i 's optimisation problem must satisfy a participation constraint

$$\underbrace{\mathcal{E}_t \left[\Psi_{it+1} F_{it} \left(\phi_{it} R_{Et+1} + (1 - \phi_{it}) R_{Et+1}^* \frac{E_{t+1}}{E_t} \right) \right]}_{\text{net share} \times \text{bank-}i \text{ gross return}} = \underbrace{\underbrace{R_{t+1}}_{\text{home riskless rate}}}_{\text{home riskless rate}} \times \underbrace{(F_{it} - N_{Bit})}_{\text{amount depositor lends to bank-}i} \quad (1)$$

Because depositors can conduct arbitrage between home and foreign riskless assets, this implies that in expectation riskless assets must yield the same return when expressed in a common currency. This implies an uncovered interest parity condition, as in Claus (2011) and Gertler, Gilchrist and Natalucci (2007)

$$R_{t+1} = \mathcal{E}_t \left(R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \quad (2)$$

Banks are risk-averse and re-optimize each period. We assume that banks maximise the expected logarithm of next-period returns subject to the participation constraint (1). Banks choose two variables⁶: total assets F_i and the contractual threshold level $\bar{\omega}_i$. Expected next-period bank profit is given by

$$\underbrace{(1 - \Gamma_{it+1})}_{\text{minus depositor's contractual share}} \underbrace{F_{it}}_{\text{portfolio of bank-}i} \underbrace{\left(\phi_{it} R_{Et+1} + (1 - \phi_{it}) R_{Et+1}^* \frac{E_{t+1}}{E_t} \right)}_{\text{return on portfolio of bank-}i}$$

So, bank- i 's optimisation problem is

$$\max_{F_i, \bar{\omega}_i} \mathcal{E}_t \left\{ \log \left[(1 - \Gamma_{it+1}) F_{it} \left(\phi_{it} R_{Et+1} + (1 - \phi_{it}) R_{Et+1}^* \frac{E_{t+1}}{E_t} \right) \right] \right\} \text{ subject to (1)}$$

⁶The portfolio allocation term ϕ_i is defined in equation (31) as an increasing function of the expected excess return on risky home assets. Hence banks treat the return on their portfolio as already having been optimised. They only explicitly choose how large that portfolio is (i.e. F_i).

This yields two first-order conditions. Combining these we get a combined first-order condition⁷

$$\mathcal{E}_t \left(\frac{R_{BANK-i\,t+1}}{R_{t+1}} \right) = \underbrace{\mathcal{E}_t \left(\frac{\frac{\Gamma_{\omega\,i\,t+1}}{\Psi_{\omega\,i\,t+1}}}{1 - \Gamma_{i\,t+1} + \Psi_{i\,t+1} \frac{\Gamma_{\omega\,i\,t+1}}{\Psi_{\omega\,i\,t+1}}} \right)}_{\text{increasing function of } \bar{\omega}} \quad (3)$$

$$\text{where } R_{BANK-i\,t+1} \equiv \text{bank portfolio return} \equiv \phi_{i\,t} R_{E\,t+1} + (1 - \phi_{i\,t}) R_{E\,t+1}^* \frac{E_{t+1}}{E_t}$$

This unwieldy equation is simply a positive relationship between (i) the threshold $\bar{\omega}_i$ (representing the depositor's contractual share of bank income) on the one hand, and (ii) the spread between the return on bank assets and the riskless rate $\frac{R_{BANK}}{R}$ (representing the profitability of bank assets) on the other. Suppose the spread on bank asset return over the riskless rate rose. Then, the bank would be able to increase its profits by expanding its balance sheet. To do this, the bank must increase its leverage. For the depositor, supplying more leverage is more costly because it increases the expected monitoring cost in case of bank- i 's default. The depositor thus demands a higher contractual share of bank income to compensate for this, hence implying a higher $\bar{\omega}_i$, as equation (3) shows.

The converse also holds. Suppose bank leverage worsened unexpectedly. The depositor must be compensated for supplying credit to a more highly-leveraged bank and thus demands a higher contractual share of bank income $\bar{\omega}_i$, which will require that the bank earn a higher spread on its portfolio above the riskless rate.

This presages our main result. Because depositors have access to both the home and foreign riskless assets, the worsening of the bank's leverage position leads to depositors demanding that the bank earn a higher spread on its portfolio above the foreign riskless

⁷We denote $\frac{d\Gamma}{d\bar{\omega}}$ and $\frac{d\Psi}{d\bar{\omega}}$ as $\Gamma_{\bar{\omega}}$ and $\Psi_{\bar{\omega}}$, and $\frac{d^2\Gamma}{d\bar{\omega}^2}$ and $\frac{d^2\Psi}{d\bar{\omega}^2}$ as $\Gamma_{\bar{\omega}\bar{\omega}}$ and $\Psi_{\bar{\omega}\bar{\omega}}$ respectively.

rate as well as the home riskless rate (i.e. $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}^* E_{t+1}/E_t} \right) \uparrow$). Since the foreign riskless rate R^* is constant (by construction) and the return on the bank's risky assets does not rise, it is the exchange rate that must bear the burden of adjustment by appreciating $\frac{E_{t+1}}{E_t} \downarrow$. A large cumulative per-period appreciation of the exchange rate along the adjustment path then implies a sharp initial depreciation (Chapter 1).

In effect, depositors withdraw funding from home banks and flood to the (home and) foreign riskless assets, causing financial outflows and a depreciation until the exchange rate is sufficiently under-valued. This is the point where the subsequent per-period appreciation of the exchange rate widens the spread between the bank's earnings and the foreign riskless rate by the necessary amount to entice depositors to keep funding the banking sector at home (rather than continue to flood to safe-haven assets). Because depositors treat home and foreign riskless assets as perfect substitutes *ex ante* (i.e. UIP holds), the extent to which home and foreign riskless rates must fall is equal, when expressed in a common currency. Hence, unsurprisingly, the spread that depositors require from banks is the same whether expressed relative to home or foreign riskless rates $\frac{R_{BANK-i}}{R} = \frac{R_{BANK-i}}{R^* E_{t+1}/E_t} \equiv \text{spread}$.

Furthermore, we can show exactly why *the presence of this friction increases exchange rate volatility*. By rearranging this expression, we can express the expected exchange rate adjustment as a function of the spread and the return on bank assets

$$\mathcal{E}_t \left(\frac{E_{t+1}}{E_t} \right) = \mathcal{E}_t \left(R_{BANK} \times \frac{1}{\text{spread}} \times \frac{1}{R^*} \right) \quad (4)$$

Suppose there is a negative shock to firm technology. Two things occur: (i) banks make a loss on their holdings of risky firm-issued assets $R_{BANK} \downarrow$ and (ii) bank leverage thus worsens and so the spread rises $\frac{1}{\text{spread}} \downarrow$. This lowers the right hand side of (4), implying that the exchange rate is expected to appreciate $\frac{E_{t+1}}{E_t} \downarrow$, as the paragraph

above explained. Suppose there was no financial friction. In this case, (i) the bank asset return falls by less (for standard closed-economy financial accelerator reasons; BGG; Kiyotaki and Moore, 1997) and (ii) there is no spread $\frac{1}{\text{spread}} \equiv 1$. So, without financial frictions, the right hand side of (4) falls by less after a negative shock, and so the short run burden of adjustment on the exchange rate is also smaller. This explicitly demonstrates why risk premia and financial frictions augment exchange rate volatility and why a larger rise in the spread $\frac{1}{\text{spread}} \downarrow\downarrow$ implies a larger jump in exchange rates (given the same long run level of the exchange rate - recall Chapter 1).

This is not an idiosyncratic feature of the BGG financial friction. Other financial frictions also generate a risk premium between the bank's earnings and riskless rates that is increasing in the bank's leverage position. We elaborate on this in section 5.2.

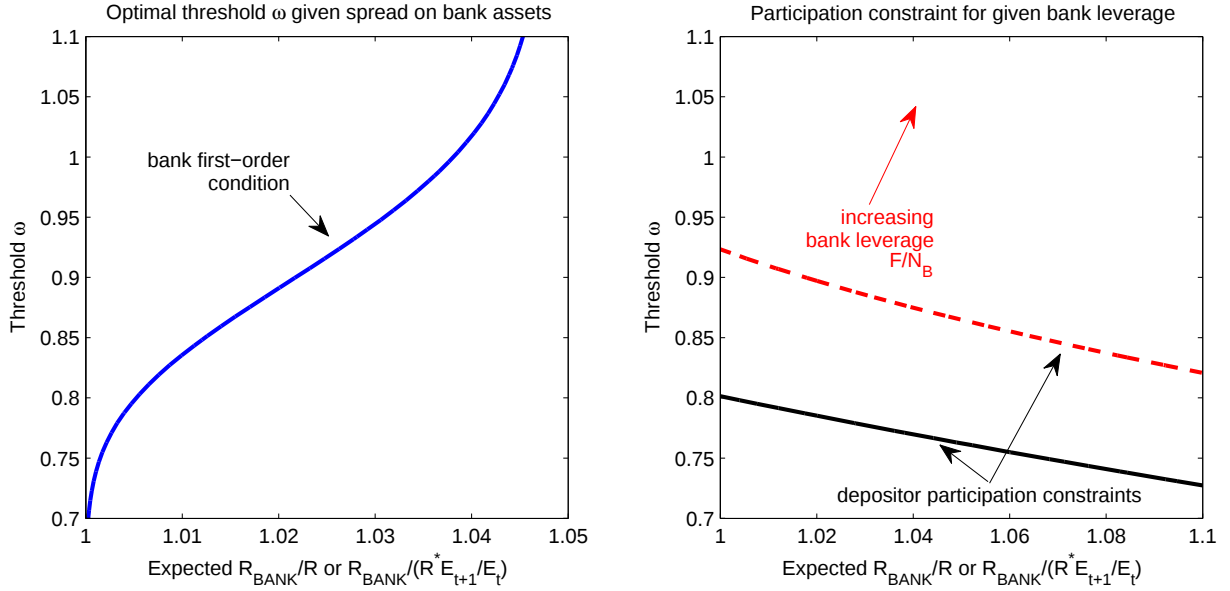
2.4 Partial equilibrium in the banking sector

The combined first-order condition and the participation constraint ((1) and (3)) are the two equations that determine partial equilibrium in the banking sector. The bank's decision is as follows. Given the spread of the asset return over the riskless rate $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}} \right)$, the bank chooses how much it is willing to pay its depositors. Given this desired repayment rate and the bank's net worth, depositors then determine how much the bank can borrow in total. We can illustrate this partial equilibrium graphically. Consider figure 2.

The left-hand panel plots the *bank's first-order condition* (3), which specifies the optimal contractual rate (i.e. $\bar{\omega}_i$) the bank wishes to pay its depositors, for a given spread $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}} \right)$ ⁸. This optimal contractual rate increases with the spread. This is

⁸This also refers to the spread of bank returns over the foreign riskless rate $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}^* E_{t+1}/E_t} \right)$ since depositors also have access to foreign riskless assets.

Figure 2: Bank's optimisation decision



because as the spread rises, bank assets become more profitable, and so the bank is willing to increase its leverage and hence its borrowing costs⁹ until the point where the marginal return of an additional unit of asset purchases equals its shadow cost.

The right-hand panel plots the *depositor participation constraint* for a given asset-to-net-worth leverage ratio $\frac{F_i}{N_{B_i}}$. These schedules represent (for a given leverage ratio of the bank) the combinations of (i) total bank profits (i.e. the spread $\mathcal{E}_t \left(\frac{R_{BANK-t+1}}{R_{t+1}} \right)$) and (ii) the depositor's contractual share of those profits (i.e. the threshold $\bar{\omega}_i$) for which the depositor is just satisfied with lending to the bank. The schedules are downward sloping since, if the spread decreases and total bank income falls, depositors demand a higher contractual share of this total income to compensate (and *vice versa*). As bank leverage increases, the entire participation constraint shifts out, and both the threshold $\bar{\omega}_i$ and the required spread rise.

The two panels of figure 2 describe partial equilibrium in the banking sector. For a

⁹As discussed, borrowing costs rise with leverage because higher leverage raises the monitoring cost for depositors and so they demand a higher $\bar{\omega}_i$ to compensate.

given spread on asset returns $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}} \right), \mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}^* E_{t+1}/E_t} \right)$ (which banks take as given), the *bank's first-order condition* specifies the maximum contractual rate that the bank is willing to pay to its lenders (left-hand panel). The *participation constraint* that passes through this point on the bank's first-order condition line then specifies the maximum leverage ratio $\frac{F_i}{N_{B,i}}$ that the bank can obtain from depositors, given the total compensation that depositors expect to receive at this point (which is a function of both the contractual share of bank income $\bar{\omega}_i$ chosen by the bank, and the total size of that bank income $\mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}} \right), \mathcal{E}_t \left(\frac{R_{BANK-i,t+1}}{R_{t+1}^* E_{t+1}/E_t} \right)$).

2.5 Evolution of aggregate bank net worth

The partial equilibrium above determined the optimal contractual share $\bar{\omega}_i$ and leverage $\frac{F_i}{N_{B,i}}$, given the aggregate variables R_E, R_E^*, R, R^* and exchange rate E . Since these macro-variables are the same for each bank, each bank makes the same decision and so we can consider the entire banking sector as an aggregate and drop the i subscript¹⁰.

And since, in aggregate, depositors (who are treated as a single aggregate entity) sign an infinite number of contracts with an infinite spectrum of banks, depositors are perfectly hedged against the idiosyncratic shocks to bank productivity. The law of large numbers obtains and so the proportion of banks that default ($F(\bar{\omega})$) and the productivity of banks that default ($G(\bar{\omega})$) are equal to their expected values.

Our discussion of the banking sector ends with an equation describing the evolution of

¹⁰The portfolio allocation ϕ_i is defined in the same way for all banks. See equation (31).

aggregate bank net worth N_B

$$N_{Bt} = \left(\underbrace{\gamma^B}_{\text{fraction not consumed}} (1 - \Gamma_t) \underbrace{F_{t-1} \left(\phi_{t-1} R_{Et} + (1 - \phi_{t-1}) R_{Et}^* \frac{E_t}{E_{t-1}} \right)}_{\text{bank's share at end of } t \text{ bank income this period}} + \underbrace{w_t^B}_{\text{bank labour income}} \right) \times \underbrace{\zeta_t}_{\text{shock}} \quad (5)$$

Equation (5) specifies the stock of home goods that the bank owns at the end of period t in preparation for purchasing assets that yield a return in period $t + 1$. The banking industry in aggregate is assumed to supply one fixed unit of labour for goods production - this assumption allows banks to accumulate net worth by receiving a labour wage. The parameter $\gamma^B \in (0, 1)$ ensures that net worth does not become so great that banks can avoid borrowing from depositors. The shock to bank net worth ζ_t follows Ueda (2012) and Gilchrist and Leahy (2002) and can be thought of as a capital quality shock as in Gertler and Karadi (2011). It follows a simple autoregressive process

$$\log(\zeta_t) = \rho^\zeta \log(\zeta_{t-1}) + \epsilon_t^\zeta \text{ where } \epsilon_t^\zeta \sim \text{iid}(0, \sigma^{\zeta^2}) \quad (6)$$

Each period, fraction $1 - \gamma^B$ of banks consume their entire net worth. The consumption of these banks is given by

$$C_{Bt} = (1 - \gamma^B) (1 - \Gamma_t) F_{t-1} \left(\phi_{t-1} R_{Et} + (1 - \phi_{t-1}) R_{Et}^* \frac{E_t}{E_{t-1}} \right) \quad (7)$$

2.6 Foreign debt and balance sheet effects

Following Gertler, Gilchrist and Natalucci (2007), we consider an alternative scenario where the home banking sector obtains all of its funding from foreign depositors¹¹. This allows us to examine the effect of foreign-denominated debt, which is a major concern of the third generation currency crisis literature (Aghion, Bacchetta and Banerjee, 2004).

In this case, the first-order condition and the *expected* depositor constraint become

$$\mathcal{E}_t \left(\frac{R_{BANK\ t+1}}{R_{t+1}^* E_{t+1}/E_t} \right) = \mathcal{E}_t \left(\frac{\frac{\Gamma_{\omega t+1}}{\Psi_{\omega t+1}}}{1 - \Gamma_{t+1} + \Psi_{t+1} \frac{\Gamma_{\omega t+1}}{\Psi_{\omega t+1}}} \right) \quad (8)$$

$$\mathcal{E}_t \left(\frac{\Psi_{t+1} F_t R_{BANK\ t+1}}{E_{t+1}} \right) = R_{t+1}^* \frac{(F_t - N_{Bt})}{E_t} \quad (9)$$

Substituting the *realised* depositor constraint into the law of motion for N_B gives

$$N_{Bt} = \left(\gamma^B (1 - \Gamma_t) R_{BANK\ t} N_{Bt-1} - \frac{R_t^* \frac{E_t}{E_{t-1}}}{R_t^* \frac{E_t}{E_{t-1}} - \Psi_t R_{BANK\ t}} + w_t^B \right) \zeta_t \quad (10)$$

It can be shown¹² from equation (10) that an unexpected depreciation in the current period lowers bank net worth. Hence “balance sheet effects” in the sense of Cespedes, Chang and Velasco (2004) do exist in this model, if debt is foreign-denominated. An unexpected depreciation in the current period lowers the value of bank net worth relative to the bank’s (foreign-denominated) liabilities.

Furthermore, the currency mismatch matters. Suppose the bank only holds foreign

¹¹The model can be extended so that the bank obtains funding from both home and foreign depositors although this would require specifying two credit contracts. We do this in Appendix 2 and in Chapter 4 (for the simpler moral hazard friction). Given that the implications are qualitatively similar, in this section we keep the analysis to one credit contract only for the sake of simplicity.

¹²Ignoring the bank net worth shock ζ and the composition of the bank portfolio return R_{BANK} , $\frac{dN_{Bt}}{dE_t} = \gamma^B (1 - \Gamma_t) R_{BANK\ t} N_{Bt-1} \frac{-\Psi_t R_{BANK\ t} R_t^*}{E_{t-1} (R_t^* \frac{E_t}{E_{t-1}} - \Psi_t R_{BANK\ t})^2} < 0$

assets ($\phi = 0$) in which case $R_{BANK\ t+1} = R_E^* \frac{E_{t+1}}{E_t}$ and the exchange rate disappears from the depositor constraint (9) and from the net worth equation (10). In other words, if there is no mismatch, an unexpected depreciation has no effect on bank net worth.

We will show in simulations that this mismatch matters. If debt is foreign-denominated, there is a negative feedback loop after negative shocks: an initial depreciation worsens leverage even more; the risk premium thus rises higher; so the exchange rate depreciates even further. Foreign debt thus augments the size of the initial depreciation. However, we will also show that financial shocks can lead to sharp falls in the exchange rate in the absence of a mismatch because spikes in risk premia can occur for unrelated reasons, as section 2.3 illustrated.

Notice that the denomination of debt matters even though the uncovered interest parity condition holds. The UIP condition equalises the *expected* home and foreign riskless rates in the next period. However, in the period when the shock occurs, the exchange rate change is *unanticipated*, and so it matters (in this initial period) whether debt is home- or foreign-denominated¹³.

3 Non-financial sector

We now turn to the non-financial sector of the model. The production side broadly follows Luk and Vines (2011). Notable differences include our extension of the model to an open economy and the specification of labour supply. The consumption side broadly follows Galí and Monacelli (2005).

¹³To be explicit, suppose there is an unanticipated depreciation at time $t = 0$. In $t = -1$, a borrower expects to repay R_0 to home lenders or $\frac{R_0^*}{E_{-1}} \mathcal{E}_{-1}(E_0)$ to foreign lenders. UIP implies that, at $t = -1$, these two *expected* rates are equal. However, after the unanticipated depreciation $E_0 > \mathcal{E}_{-1}(E_0)$, the *realised* rate abroad exceeds the *realised* rate at home and so the value of foreign-denominated debt would be higher than that of home-denominated debt.

3.1 Households

The representative household faces a per-period budget¹⁴

$$\begin{array}{ccccccc}
 \underbrace{P_t C_t}_{\text{consumption}} & + & \underbrace{B_{Ht} P_t + B_{Ft} P_t \frac{1}{E_t}}_{\text{deposits}} & \leq & \underbrace{R_t B_{Ht-1} P_t + R_t^* B_{Ft-1} P_t \frac{1}{E_{t-1}}}_{\text{return on last-period}} & + & \underbrace{w_t L_t}_{\text{labour income}} & + & \underbrace{\Pi_t}_{\text{bank \& capital goods producer profits}} \\
 \text{in terms of} & + & \text{in terms of} & \leq & \text{deposits in terms of} & + & & + & \\
 \text{home goods} & & \text{home goods} & & \text{home goods} & & & &
 \end{array} \tag{11}$$

We assume that aggregate labour supply is a mixture of two types of workers

$$L_t = l_t^\nu l_{t-1}^{1-\nu} \tag{12}$$

Some proportion ν of the workers in the representative household are free to adjust their hours worked each period. The other $1 - \nu$ fraction of workers follow a “rule-of-thumb” such that they work as many hours as was optimal in the previous period. A simple way to motivate this is to suppose that a fraction of the workers have to sign long-term labour contracts that specify their labour supply for more than one period.

We introduce this friction because we need some degree of rigidity in the labour supply in order to get intuitive results. In the absence of this rigidity (i.e. $\nu = 1$), a negative financial shock leads to a rise in output. This is because the shock generates a large depreciation of the exchange rate, which pushes up net exports, counteracting the effect

¹⁴Following Gertler, Gilchrist and Natalucci (2007), we attach a small premium to the foreign riskless rate R^* which is increasing in total net household indebtedness. This ensures stationarity of this small open economy model (Schmitt-Grohe and Uribe, 2003). We set the elasticity of this premium with respect to net debt close enough to zero such that this does not affect the model dynamics but ensures that household debt (and hence consumption) revert to trend. R^* varies by a sufficiently small margin in our simulations that it can be thought of as constant.

of the shock (Aghion, Bacchetta and Banerjee, 2004). This is accommodated by a large increase in hours worked that raises production of the home good. Making the labour supply slow to adjust minimises this effect. This issue is related to the result of Chari, Kehoe and McGrattan (2005), who find that sudden stops in capital flows do not cause output to fall, unless there is another type of friction in the model.

The household's optimisation problem is thus

$$\max_{C_i, l_i, B_{Hi}, B_{Fi}} \left\{ U_t = \mathcal{E}_t \sum_{i=t}^{\infty} \beta^{t-i} \left[\log(C_i) - \chi \frac{(l_i^\nu l_{i-1}^{1-\nu})^{1+\psi}}{1+\psi} \right] \right\} \text{ subject to (11)}$$

This gives a familiar looking Euler equation, an intertemporal labour supply equation, and an arbitrage condition which we presented above (the UIP condition (2))

$$\mathcal{E}_t \left(\frac{C_t R_{t+1}}{C_{t+1}} \right) \beta = 1 \quad (13)$$

$$\begin{pmatrix} \chi \nu l_{t-1}^{(1-\nu)(1+\psi)} l_t^{\nu(1+\psi)-(1-\nu)} \\ -\nu \frac{w_t}{P_t C_t} l_{t-1}^{1-\nu} l_t^{2\nu-1} \end{pmatrix} = \beta \mathcal{E}_t \begin{pmatrix} -\chi (1-\nu) l_{t+1}^{\nu(1+\psi)} l_t^{\psi(1-\nu)} \\ + (1-\nu) \frac{w_{t+1}}{P_{t+1} C_{t+1}} l_{t+1}^{1+\nu} \end{pmatrix} \quad (14)$$

Equation (14) has a backward-looking and a forward-looking component. The decision of the workers free to adjust their hours depends on last period's choice because this affects the determination of the wage this period. Their decision also depends on the expected real wage next period because they take into account the chance that in the next period they may be unable to change their hours. Setting $\nu = 1$ collapses equation (14) to a familiar labour supply condition for a flexible labour market $\chi L_t^\psi = \frac{w_t}{P_t C_t}$.

3.2 Consumption

The Euler equation (13) determines the path of aggregate consumption. Within each period, consumption is split between home- and foreign-produced goods. Following Gali and Monacelli (2005), we assume that aggregate consumption is a constant elasticity of substitution index of home- and foreign-produced goods

$$C_t = \left[\gamma^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

and the same for the price index

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1-\gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (15)$$

where γ represents home bias in goods consumption and η is the price elasticity of substitution between home and foreign goods. P_H and P_F are the prices paid by the home household for home and foreign goods.

It is straightforward to show that domestic demand for home and foreign goods is given by, respectively,

$$C_{Ht} = \gamma C_t \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (16)$$

$$C_{Ft} = (1-\gamma) C_t \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} \quad (17)$$

External demand for home-produced goods is given by (following Gertler, Gilchrist and Natalucci [2007])

$$C_{Ht}^* = \bar{C}_H^* \left(\frac{P_{Ht}}{E_t} \right)^{-\eta} \quad (18)$$

We treat the home good as a numeraire ($P_H = 1$) (Sa and Viani, 2013) and we assume that the law of one price holds so the home consumer pays a price $P_{Ft} = E_t$ for foreign goods and foreign consumers pay a price $\frac{P_H}{E}$ for home goods (Gali and Monacelli, 2005).

3.3 Firm

The home goods-producing firm employs a Cobb-Douglas technology

$$Y_t = A_t K_t^\alpha L_t^{(1-\alpha)(1-\Omega_E-\Omega_B)} L_{Et}^{(1-\alpha)\Omega_E} L_{Bt}^{(1-\alpha)\Omega_B} \quad (19)$$

where the exogenous level of productivity with mean $\bar{A}$ follows the process

$$\log(A_t/\bar{A}) = \rho^A \log(A_{t-1}/\bar{A}) + \epsilon_t^A \text{ where } \epsilon_t^A \sim \text{iid}(0, \sigma^2) \quad (20)$$

L_E, L_B are hours worked by the firm and the banking sector and are normalised to one at every period. Ω_E and Ω_B are the shares of labour supply contributed by the firm and by banks.

We assume that the firm must purchase capital one period in advance. It funds this capital purchase in period t by issuing assets to banks that pay a return R_E after production has taken place in $t + 1$. At the same time, it sells any non-depreciated capital back to capital producers. The firm thus solves, subject to the production function (19)

$$\max_{K, L, L_E, L_F} \left\{ \mathcal{E}_t \left[Y_{t+1} - w_{t+1} L_{t+1} - w_{t+1}^E L_{Et+1} - w_{t+1}^B L_{Bt+1} + (1 - \delta) Q_{t+1} K_{t+1} - R_{Et+1} Q_t K_{t+1} \right] \right\}$$

where w , w^E , and w^B are labour wages, and Q is the price of capital (Tobin's Q)¹⁵.

¹⁵Notice that the firm's decision on how much capital to purchase in t for $t + 1$ depends on its

This yields an equation describing demand for household-labour

$$w_t = (1 - \alpha)(1 - \Omega_E - \Omega_B) \frac{Y_t}{L_t} \quad (21)$$

and wage equations for firms and for banks (recall that $L_E = L_B = 1$)

$$w_t^E = (1 - \alpha) \Omega_E Y_t \quad (22)$$

$$w_t^B = (1 - \alpha) \Omega_B Y_t \quad (23)$$

The realised return on capital is

$$R_{Et} = \frac{1}{Q_{t-1}} \left((1 - \delta) Q_t + \alpha \frac{Y_t}{K_t} \right) \quad (24)$$

Firms have net worth N_{Et} that evolves according to

$$N_{Et} = \gamma^E R_{Et} N_{Et-1} + w_t^E \quad (25)$$

where parameter $\gamma^E \in (0, 1)$ ensures that N_E never becomes so large that the firm can internally finance all capital purchases.

The firm consumes proportion $1 - \gamma^E$ of its entire net worth (following Luk and Vines [2011])

$$C_{Et} = (1 - \gamma^E) R_{Et} N_{Et-1} \quad (26)$$

expectation of how much labour it will employ next period, even though the decision of how much labour to employ is made within the period in which production takes place. This is because the firm's expected labour demand affects its expectation of how productive capital will be next period.

3.4 Capital goods producer

Capital evolves according to

$$K_{t+1} = (1 - \delta) K_t + I_t - \frac{\xi (K_{t+1} - K_t)^2}{2 K_t} \quad (27)$$

where parameter ξ represents adjustment costs, I is investment, and δ is the rate of depreciation. At the end of each period t , home firms purchase stock K_{t+1} of capital goods for production in the next period. At the same time, capital goods producers buy back the undepreciated stock of capital from the current period at the prevailing price. They also purchase I_t units of home goods at price P_{Ht} and combine these with the undepreciated capital to build next period's capital stock.

This implies that capital goods producers solve

$$\max_{I_t} \{Q_t K_{t+1} - (1 - \delta) Q_t K_t - P_{Ht} I_t\} \text{ subject to (27)}$$

This yields the first-order condition

$$Q_t = P_{Ht} \left(1 - \xi + \xi \frac{K_{t+1}}{K_t} \right) \quad (28)$$

3.5 General equilibrium conditions

Goods market equilibrium is given by equating the supply of and demand for the home good

$$Y_t = C_{Ht} + C_{Ht}^* + C_{Et} + C_{Bt} + I_t + \mu G(\bar{\omega}_t) F_{t-1} R_{BANKt} \quad (29)$$

where the final term is the monitoring cost paid by depositors in equilibrium.

Equilibrium in the market for the home asset is given by equating the amount of financial intermediation demanded by the home firm with the amount of financial intermediation supplied by the home bank and foreign investors

$$Q_t K_{t+1} - N_{Et} = \phi_t F_t + F_t^* \quad (30)$$

where F^* is foreign demand for home assets and is treated exogenously. Following our specification in Chapter 2 (and following Meredith [2007] and Sa and Viani [2013]), the bank allocation of its portfolio between home and foreign risky assets is determined by the function ϕ_t

$$\phi_{it} = \bar{\phi} \mathcal{E}_t \left(\frac{R_{Et+1}}{R_{Et+1}^* \frac{E_{t+1}}{E_t}} \right)^\kappa \quad \forall i \quad (31)$$

where $\kappa > 0$ denotes the elasticity of substitution between assets. Bank demand for home assets is increasing in the expected excess return on home assets. This implies some imperfect substitutability between home and foreign risky assets from the perspective of the bank. In Appendix 2, we show that this imperfect substitutability arises from the bank choosing its portfolio so as to hedge against changes in funding costs. For our simulations, we set κ at a sufficiently high value such that this imperfect substitutability does not affect model dynamics¹⁶.

The model consists of the equations (1)-(3), (5)-(7), and (12)-(31). For the alternative scenario of foreign bank debt, we replace (1) and (3) with (8) and (9). These equations

¹⁶The purpose of having this $\phi \in (0,1)$ term (rather than simply setting $\phi = 1$ or $\phi = 0$) is to examine the effect of the currency mismatch on bank balance sheets. Imperfect substitutability is not our main concern.

determine the equilibrium dynamics of the variables

$$\left\{ \begin{array}{l} E_t, R_{Et}, R_t, \bar{w}_t, F_t, \phi_t, N_{Bt}, N_{Et}, Y_t, K_t, Q_t, I_t, L_t, l_t, \\ w_t, w_t^E, w_t^B, P_t, C_t, C_{Ht}, C_{Ft}, C_{Ht}^*, C_{Et}, C_{Bt}, A_t, \zeta_t \end{array} \right\}_{t=0}^{\infty}$$

given exogenous innovations to A_t, R_{Et}^* , and the shock to bank net worth ζ_t .

4 Response to a financial crisis

We have built a model of a small open economy with a banking sector and financial frictions. The model is solved using standard linear perturbation techniques¹⁷. A log-linearised version of the model is listed in Appendix 1. We consider two shocks to the system: (i) an innovation to bank net worth ζ_t as in Ueda (2012) and Gilchrist and Leahy (2002) and (ii) a standard innovation to productivity A_t .

4.1 Parameterisation

We assume four steady state targets regarding the financial sector. We set these targets to match Australian data so that we find a parameterisation that roughly conforms with a small open economy

- External finance premium $(\bar{R}_E - \bar{R}) = 0.00495$. We choose this to match an annual risk spread of 198 basis points, which is the historical average spread of the Australian bank lending rate (to large non-financial corporations) over the 2-year sovereign bond yield.

¹⁷See our discussion in 4.2 of the Introduction for a discussion of this solution method.

Table 1: Computed and calibrated parameters

Parameter/variable	Value	Source
Monitoring cost μ	0.0406	computed using targets
Steady state threshold $\bar{\omega}$	0.7901	“
ω standard deviation σ^ω	0.1149	“
Firm survival parameter γ^E	0.9836	“
Bank survival parameter γ^B	0.9638	“
Capital share of income α	0.35	BGG
Discount factor β	0.99	“
Depreciation rate δ	0.025	“
Firm and bank labour supply share Ω_B, Ω_E	0.01	“
Capital adjustment cost ξ	10	“
Price elasticity of substitution η	1.5	Engel and Matsumoto (2009)
Frisch elasticity of labour supply ψ	0.33	Hirakata <i>et al.</i> (2011)
Utility weight on labour supply χ	0.3	“
Home bias in consumption γ	0.85	see Chapter 2
Rigidity in labour supply $1 - \nu$	0.20	see below
Elasticity of bank asset allocation κ	10	“
Steady state domestic share of bank assets $\bar{\phi}$	0.874	Australian data
Shock to bank net worth	-0.0761	“

- Entrepreneurial leverage $\frac{\bar{K}}{\bar{N}_E} = 2.1$. Capital-to-bank-net-worth-ratio $\frac{\bar{K}}{\bar{N}_B} = 9.2$. These are chosen to match the averages (over 1995-2004), respectively, of the ratio of Australian non-financial corporation assets to equity, and the ratio of non-financial corporation assets to financial corporation equity.
- Bank default rate $F(\bar{\omega}) = 0.0231$. This is chosen to match the implied default probability of Australian banks in 2007, as measured by Allen and Powell (2012).
- To compare: the values chosen by BGG and Hirakata *et al.* to match US data are similar. $(\bar{R}_E - \bar{R}) = 0.005$, $\frac{\bar{K}}{\bar{N}_E} = 2$, $\frac{\bar{K}}{\bar{N}_B} = 10$, $F(\bar{\omega}) = 0.02$.

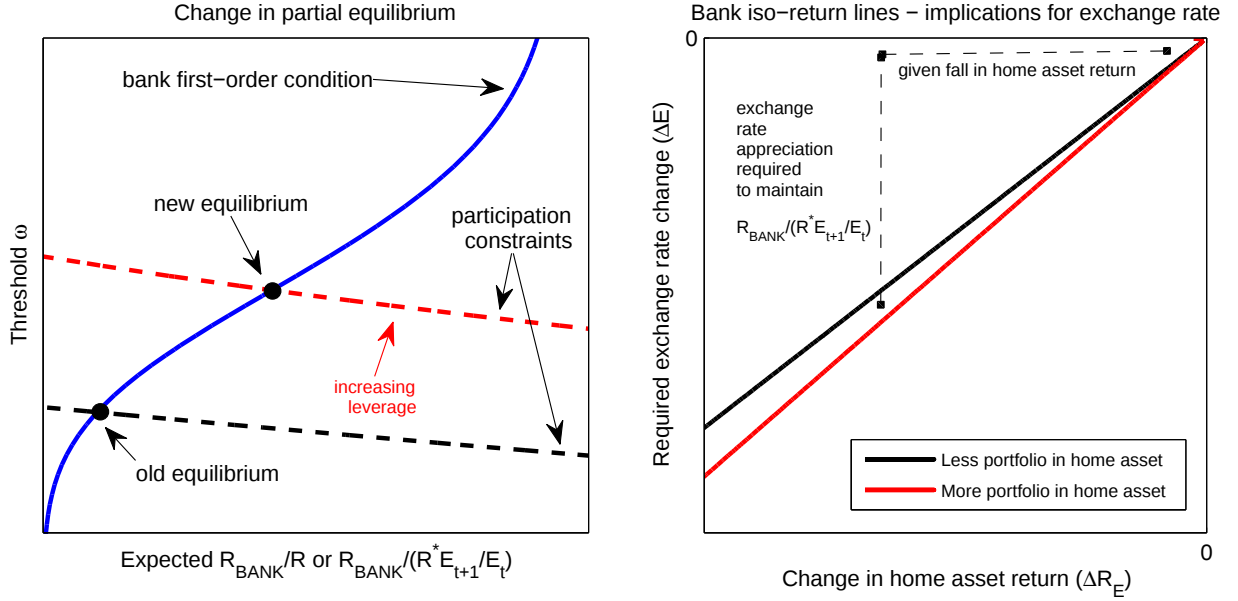
We set the remaining parameters using the values in table 1, which allows us to compute the steady state values of variables:

- $\alpha, \beta, \psi, \gamma, \eta, \delta, \xi$. These are all values chosen by BGG except for the elasticity

of labour supply ψ , which is the value chosen by Hirakata *et al.*. All values are within standard ranges the literature (e.g. Cooley, Hansen & Prescott 1995).

- Ω_E, Ω_B . Firm and bank share of labour supply are both taken as 0.01, from BGG.
- $1 - \nu$. The degree of rigidity in labour supply is set at 0.50, implying that around 50% of workers are free to change their hours worked each period. There is little consensus on how to calibrate the degree of real wage or real labour rigidity. Blanchard and Gali (2010) also choose a midpoint value of 0.5 to reflect real rigidity in labour markets. In this model, we find that the results are quantitatively similar for any value of $1 - \nu \in [0.2, 1.0]$. That is, as long as the labour market is not completely flexible, the same results go through. Our chosen value implies a contract length of ~ 8 months, which is very conservative. Rich and Tracy (2004) find that the median contract duration in the US is ~ 35 months.
- κ . The elasticity between home and foreign risky assets in the bank's portfolio allocation is set at 10. This is a reasonably high level that means that the implied imperfect substitutability between home and foreign risky assets does not affect model dynamics significantly. Our simulation results are quantitatively robust for the values of $\kappa \in [0, 20]$.
- $\bar{\phi}$. Steady state domestic share of bank assets is set at 87.4%. This is chosen to match the 2000-7 domestic share of commercial bank assets in Australia. In Appendix 2 we solve for the optimal portfolio of the bank, parameterised with Australian data, and show that it predicts a similar value for $\bar{\phi}$. We also simulate experiments for $\bar{\phi} = \{17\%, 57\%\}$ in order to replicate lower levels of currency mismatch in the alternative scenario when bank debt is foreign-denominated.
- The shock we simulate is a temporary, unanticipated fall in bank net worth of

Figure 3: Response of depositors and banks to change in bank net worth



7.61% (an innovation to ζ). This is chosen to match the average fall in equity values between Q2 to Q3 2008 of the big four commercial banks in Australia, weighted by market capitalisation.

4.2 Revisiting the banking sector partial equilibrium

We simulate a negative shock to bank net worth. Before we turn to the numerical simulations below, we can use the partial equilibrium analysis of the banking sector from section 2.4 in order to examine the effect of this shock on the exchange rate.

Consider figure 3. The left-hand panel plots the familiar banking sector partial equilibrium diagram from section 2.4. The original equilibrium is represented by the intersection of the bank's first-order condition (blue curve) and the original depositor participation constraint (dashed black line). Because of the exogenous fall in bank net worth N_B , the aggregate leverage position of banks worsens $\frac{F}{N_B} \uparrow$. A worsening of

the bank's leverage position means that depositors face higher monitoring costs in the event of default. To compensate for this, depositors demand some combination of a higher contractual share of bank income (denoted by the threshold $\bar{\omega}$) and a higher profitability of bank assets (denoted by the spreads on bank earnings over the riskless rates $\frac{R_{BANK}}{R}, \frac{R_{BANK}}{R^* E_{t+1}/E_t}$). Hence, in the left-hand panel of figure 3, the entire depositor participation constraint shifts out to the position indicated by the dashed red line.

If this was a purely partial equilibrium model and leverage was an endogenous choice of the banks only, banks would optimally respond by deleveraging, causing the participation constraint to shift back to its original position. However, this is a general equilibrium model, in which leverage is determined by other factors that are outside the control of the bank (namely, the slow adjustment of the home capital stock), and so leverage remains elevated and the participation constraint remains shifted-out. Given this constraint, banks optimise by choosing a threshold $\bar{\omega}$ that lies on their first-order condition.

The result is that the banking sector partial equilibrium shifts up and right to the intersection of the bank's first-order condition and the new participation constraint (dashed red line). Both the threshold $\bar{\omega}$ and the expected spread on bank earnings over riskless rates rise. This can only be an equilibrium outcome if (in general equilibrium) the actual spreads rise $\frac{R_{BANK}}{R}, \frac{R_{BANK}}{R^* E_{t+1}/E_t} \uparrow$ so that bank profits increase to meet the higher funding costs they now face ($\bar{\omega} \uparrow$). In the simulations, we see that the absolute return on bank assets falls $R_{BANK} \downarrow$. This is because bank demand for home assets falls, which pushes down the price of capital and thus lowers the return on home assets R_E . So, in order for the spreads to rise, it must be the riskless rates that adjust. The home riskless rate falls. However, the foreign riskless rate R^* is constant (by construction) and so the exchange rate must also bear the burden of adjustment.

The *exchange rate appreciates along the adjustment path* $\frac{E_{t+1}}{E_t} \downarrow$. This raises the foreign value of the bank's earnings, widening the spread between the bank's return and the foreign riskless rate $\frac{R_{BANK}}{R^* E_{t+1}/E_t} \uparrow$, which keeps depositors satisfied with funding the bank at its heightened leverage ratio. Recall from Chapter 1 that a large cumulative per-period appreciation of the exchange rate may imply a large initial depreciation. We will see in the simulations that the cumulative appreciation along the adjustment path is sufficiently large that the exchange rate does initially depreciate sharply. Hence financial frictions generate spikes in risk premia that give rise to large volatile jumps of the exchange rate.¹⁸

We can attach an intuitive *causal structural explanation* to this exchange rate movement. What is occurring is that depositors, observing a more highly-leveraged banking sector, withdraw deposits from home banks and flood to the riskless assets abroad. This causes financial outflows and a depreciation. This depreciation occurs until the point at which the exchange rate is sufficiently under-valued. This is where the subsequent per-period appreciation raises the spread between the bank's earnings and the foreign riskless rate $\frac{R_{BANK}}{R^* E_{t+1}/E_t} \uparrow$ by the necessary amount to keep depositors satisfied with supplying funding to the banking sector (instead of saving risklessly overseas). Financial outflows stop and inflows resume, causing the exchange rate to gradually appreciate on its out-of-steady-state adjustment path.

Similarly, depositors also flood to riskless assets at home. This causes the home riskless

¹⁸For simplicity of analysis, we have assumed that the world interest rate does not move and hence the burden of adjustment fell solely on the exchange rate. This would suit the situation where the financial crisis is contained within the domestic country. But a global crisis like the 2008 crisis would cause the world interest rate to also fall. There are two responses to this critique. First, we can show through numerical simulations that the results are not qualitatively different if we simultaneously model an exogenous fall in the foreign riskless rate (R^*) and the foreign asset return (R_E^*) at the same time as the fall in home bank net worth. The second response to this critique is that, in a global crisis, there would typically be a “flight to safety” effect as capital flowed to safe havens such as the United States. In this case, even though riskless rates in the US fell, US creditors would still be less willing than previously to supply credit to foreign small open economies.

rate R to fall until the point at which the spread between the bank's return and the home riskless rate is sufficiently large to entice depositors to keep funding banks $\frac{R_{BANK}}{R} \uparrow$. As depositors begin to move out of the home riskless asset, the riskless rate then begins to rise and return back to its steady state level.

Because depositors treat the home and foreign riskless assets as perfect substitutes *ex ante* (i.e. UIP holds), the extent to which the home and foreign riskless rates fall is equal in expectation (when expressed in a common currency) $R \downarrow = R^* \frac{E_{t+1}}{E_t} \downarrow$. Hence, unsurprisingly, arbitrage conducted by depositors ensures that the spread that banks must earn is the same whether expressed relative to home or foreign riskless rates $\frac{R_{BANK}}{R} = \frac{R_{BANK}}{R^* E_{t+1}/E_t}$.

There is one final thing to note. The right-hand panel of figure 3 visualises how large the per-period appreciation of the exchange rate has to be. The lines in this panel represent, for any fall in the return on the home asset $R_E \downarrow$, how much the exchange rate must appreciate $\frac{E_{t+1}}{E_t} \downarrow$ in order to widen the spread between the bank's return and the foreign riskless rate by a given amount $\frac{R_{BANK}}{R^* E_{t+1}/E_t} \uparrow$. Notice that, when the bank holds a higher proportion of its portfolio in the home asset (red line), the expected appreciation has to be bigger (i.e. more negative). This is because the bank makes a greater loss on its portfolio and hence the appreciation has to be larger in order to maintain the same bank income. This implies that a higher currency mismatch in the bank's balance sheet (holding more home assets and fewer foreign assets) increases the burden of adjustment on the exchange rate. We would thus expect that a higher currency mismatch would increase the volatility of the exchange rate.

4.3 Simulation of a bank net worth shock

We now illustrate the discussion above with numerical simulations. In figures 5 and 6 (figures at end of section) we present simulations of a temporary negative shock to bank net worth (ζ). We impose a simple autoregressive structure on the shock with an autoregressive coefficient of $\rho^\zeta = 0.8$.

Financial sector and the exchange rate (figure 5)

Consider figure 5. In response to the shock, *bank net worth* immediately falls. It continues to decline due to the persistence of the shock and also due to the fact that funding costs have risen, which will have a further detrimental impact on bank net worth. The *bank's leverage* thus worsens and remains elevated even though the bank wishes to deleverage. This is because the stock of capital goods is slow to adjust. This means that the bank has to supply a similar level of financial intermediation to the goods-producing sector after the shock as before but now with lower net worth to fund asset purchases. Hence the size of bank assets relative to bank net worth remains high after the shock and is slow to fall.

Because the bank's leverage position has worsened, depositors demand a combination of (i) a higher contractual share of bank profits and (ii) higher total bank profits in order to compensate for higher monitoring costs in case of default. Hence the *threshold* $\bar{\omega}$ rises, as does the *spread on bank assets over the riskless rates*. Because the return on bank assets R_{BANK} falls, the widening of the spread $\frac{R_{BANK}}{R}, \frac{R_{BANK}}{R^* E_{t+1}/E_t} \uparrow$ requires that the riskless rates move. That is, the *home riskless rate* falls and (because the foreign riskless rate is constant) the *exchange rate* undergoes a per-period appreciation along the adjustment path $\frac{E_{t+1}}{E_t} \downarrow$, which raises the foreign value of the home bank's return at

every period after the shock. The cumulative size of this per-period appreciation along the adjustment path is sufficiently large relative to the medium-run level of the exchange rate¹⁹ that the exchange rate initially jumps and depreciates sharply to accommodate the subsequent adjustment (recall Chapter 1). Because UIP holds, the extent to which the home and foreign riskless rates fall is equal in expectation, when expressed in a common currency $R \downarrow = R^* \frac{E_{t+1}}{E_t} \downarrow$. Hence, unsurprisingly, the spread that the bank must earn is the same whether expressed relative to home or foreign riskless rates $\frac{R_{BANK}}{R} = \frac{R_{BANK}}{R^* E_{t+1}/E_t}$.

The *structural causal explanation* of the behaviour of the exchange rate and the home riskless rate is straightforward. Because the home banking sector is now more highly leveraged, lenders withdraw deposits and flock to foreign riskless assets, causing financial outflows and a depreciation of the exchange rate. The outflows continue until the exchange rate is sufficiently depreciated. This is the point where the subsequent per-period appreciation widens the spread between bank earnings and the foreign riskless rate sufficiently to entice creditors to continue funding the home banking sector (rather than flooding to safe-haven assets abroad). The outflows stop and inflows resume, causing the exchange rate to then appreciate gradually along the adjustment path. We can interpret the initial depreciation as reflecting the extent to which the home currency has to be under-valued in order to entice depositors to extend credit to a now more-leveraged domestic banking sector. Similarly, depositors also flood to the home riskless asset. This pushes down the home riskless rate until it is sufficiently low that the spread between it and the bank's return is high enough to entice depositors to continue funding banks.

¹⁹The medium-run level of the exchange (after about 40 quarters) is very slightly appreciated. By this time, the financial sector is back to steady state since bank leverage has returned to its original level. So, at this time, it is the non-financial sector that is driving the results. Because the supply of the home good falls slightly in the medium-run, the level of the exchange rate is appreciated (relative to steady state) in order to clear goods markets.

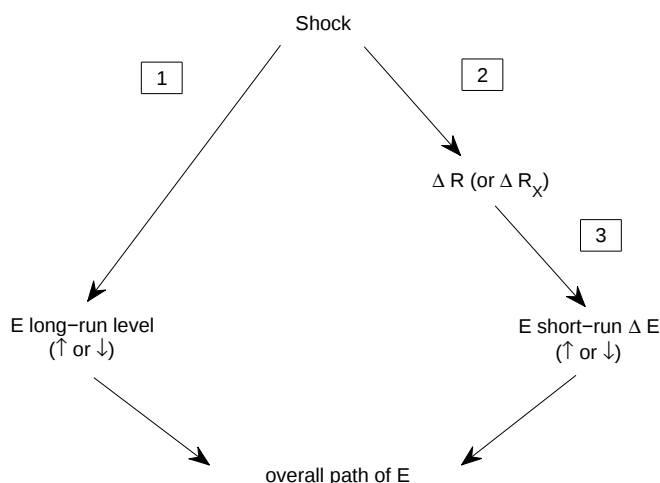
Because the depositor's contractual share of bank income rises, so does the *contractual rate* at which banks borrow from depositors. Because funding costs rise, banks deleverage, shrinking both the *assets* and *liabilities* on their balance sheet. Notice that this process is slow for the reasons mentioned above. The home capital stock in the goods-producing sector is slow to decumulate and so banks cannot reduce the size of balance sheets to the desired leverage ratio immediately.

Exchange rate summary

For the purpose of continuity, we can map the exchange rate movement described above to the familiar schematic seen in the other Chapters, here reproduced in figure 4. Consider the first arrow. Because the shock here is only temporary, we are interested in the medium-run rather than the long-run level (which is simply zero) of the exchange rate. The negative shock causes the supply of home goods to contract slightly in the medium run (when all financial sector variables are back to steady state and only the non-financial sector variables are out of steady state) and so the exchange rate is at a very mildly appreciated level. That is, the price of home goods rises slightly to clear goods markets in the medium run.

Consider the second arrow. As discussed at length above, the negative shock causes the banking sector to become more highly-leveraged. Creditors demand a higher spread between bank earnings and riskless rates. The third arrow follows from the second. Because the foreign riskless rate is constant, the exchange rate bears the burden of adjustment and appreciates along the adjustment path. The cumulative size of this per-period appreciation is large. Crucially, it is larger than the medium-run level appreciation and hence the exchange rate initially depreciates sharply, reflecting the extent of capital flight out of the country until the currency is sufficiently under-valued to entice

Figure 4: Exchange rate determination



capital back to the home banking sector. The exchange rate then gradually appreciates as capital flows back into the home country.

Non-financial sector (figure 6)

Consider the non-financial sector in figure 6. Because of the fall in bank demand for home assets, the *price of capital* Q falls before recovering as the decumulation of capital causes the marginal product of each remaining unit of capital to rise. Because the price of capital falls, holders of home assets suffer an unanticipated loss and so the *return on home assets* R_E falls initially. R_E recovers very quickly because Q is rising on the adjustment path, which gives rise to a capital gain on holding home assets. *Investment* in capital goods follows the path of Q . Because of the fall in investment, the *capital stock* gradually falls, before recovering as investment recovers.

The fall in the capital stock lowers the marginal product of labour and thus also the *hours worked*. *Output* falls due to lower labour supply and capital. The fall in output is only moderate. This is due to the effect discussed in section 3.1: net exports rise

significantly after the exchange rate depreciation. *Firm net worth* initially falls because of the unanticipated loss on capital goods (Q falls) but it then recovers as Q rises. Furthermore, firm net worth must rise above its original level because banks are supplying less financial intermediation even though the stock of capital goods is slow to adjust. So it must be the case that firms are internally financing their capital purchases by accumulating net worth through retained earnings.

The growth rate of *consumption* is determined by the riskless rate while *imports* and *exports* follow, in opposite directions, the real exchange rate. Household utility (i.e. the net present value of household utility, as in Gertler and Karadi [2011]) falls as a result of lower consumption and the expectation of higher hours worked in the future.

The shock is very persistent, taking ~ 20 years for the system to return to steady state. This is due to the time taken by the bank to decrease borrowing following the spike in borrowing costs and then to increase borrowing again when its balance sheet recovers. This is compounded by the capital adjustment costs that lengthen the time required to decrease and then rebuild firm capital.

How “large” is the $\sim 8\%$ fall in the real exchange rate under this shock? One way we can answer this question is to examine the size of the responses of other variables. In particular, output falls by $\sim 2.5\%$. Volatility (on a relative basis) is clearly larger than that exhibited in the earlier Chapters. In Chapters 1 and 2, a 3% fall in output only leads to exchange rate jumps of $\sim 0.5\%$ and $\sim 1.5\%$ respectively. In 2008, the UK real effective exchange rate fell by a much larger $\sim 15\%$ but this was accompanied by a much larger $\sim 5\%$ fall in output, which suggests that the size of the shock itself was much larger. Indeed, the average REER standard deviation in G10 small open economies is only $\sim 4.5\%$ in the period from 1994 to 2007²⁰. We can thus reasonably

²⁰We apply a (monthly) Hodrick Prescott filter to BIS REER data from January 1994 to December

say that the exchange rate volatility generated by our model is large when compared with the size of the change in output and also when compared with typical observed changes in exchange rates in the pre-crisis period.

4.4 Effect of the currency mismatch

In figures 7 and 8, we simulate the same net worth shock as in the previous section but under the alternative scenario where bank debt is foreign-denominated. Recall that this makes a difference even though UIP holds because the *unanticipated* exchange rate depreciation in the first period after the shock causes a fall in bank net worth relative to foreign goods, even though *in expectation* home and foreign riskless rates are always equal. Hence we see that while the responses of all variables are qualitatively identical, the quantitative effect of the shock is magnified.

The blue lines in figures 7 and 8 represent the case where $\bar{\phi} = 87\%$, as before. In the financial sector (figure 7), bank net worth falls by more than in the previous figures because of the “balance sheet effect” of the unanticipated depreciation. This creates a negative feedback loop: the initial depreciation worsens bank leverage, leading to a higher required spread on bank earnings, which implies a larger cumulative per-period appreciation of the exchange rate and hence an even larger initial depreciation of the exchange rate. Thus we see in figure 7 that the exchange rate initially depreciates sharply by over 12%. A larger fall in bank net worth of course also implies a higher rise in leverage and so the responses of the other financial sector variables ($\bar{\omega}$, $\frac{R_{BANK}}{R}$) are also magnified under foreign-denominated debt. In the non-financial sector (figure 8): this larger fall in bank net worth under foreign-denominated debt also leads to a larger

2007. We include: Belgium, France, Germany, Italy, Netherlands, Sweden, and the UK. We exclude Canada (because of the effect of commodities), Japan (because of the lingering effects of its 1991 financial crisis), and the US (because it is arguably not a small open economy).

fall in the price of capital (because bank demand for assets falls by more) and thus the effect of the shock on the non-financial sector is also greater.

The red lines in figures 7 and 8 represent the same shock, but with lower degree of currency mismatch in the bank balance sheet. The solid red line represents the case where the bank only holds 57% of its portfolio in home assets. The dashed red line represents the case where the bank holds 17% of its portfolio in home assets (with the majority 83% in foreign assets). Clearly, lowering the currency mismatch dampens the initial jump in the exchange rate. The reason for this is that the initial depreciation now has less of a detrimental effect on net worth because the bank's assets are also largely foreign-denominated and so the bank is hedging against denomination risk. A smaller fall in bank net worth under a smaller mismatch then implies a lesser rise in leverage and so the responses of the other financial sector variables ($\bar{\omega}$, $\frac{R_{BANK}}{R}$) are also dampened. In the non-financial sector (figure 8): because bank net worth falls by less when the mismatch is smaller, the price of capital also falls by less and thus the effect of the shock on the non-financial sector is accordingly smaller. The prediction of the old Asian Crisis literature is relevant. A smaller currency mismatch dampens the detrimental “balance sheet effect” of the unexpected depreciation.

However, contrary to the old currency crisis models, our simulations also show that even a small mismatch (as in the case with the dashed red lines) can generate a large fall in exchange rates after a financial shock. Indeed, even when we completely eliminate the currency mismatch with home-denominated debt (as in our original simulations in figures 5 and 6) the negative financial shock still gives rise to a significant initial drop in the exchange rate ($\sim 8\%$). Regardless of the denomination of assets and liabilities, as long as depositors are able to divert their funding abroad, banks have to earn a higher return relative to the foreign riskless rate if leverage worsens. And if the foreign

riskless rate does not move, it is the exchange rate that has to bear the burden of adjustment. Thus financial shocks can generate volatile jumps in the exchange rate for reasons other than the mismatch. This is important because it means that, even though bank currency mismatches are reasonably small (see panels C and D of table 2 and Bleakley and Cowan [2008] for emerging markets), exchange rates remain highly vulnerable to financial shocks. In Appendix 2, we solve for the optimal steady state portfolio of the bank and show that this model also predicts that banks minimise the mismatch on their balance sheets.

4.5 Comparison with a technology shock

In this section, we compare the bank net worth shock of the previous sections with a technology shock. We return to our baseline case of home-denominated bank debt. We consider a temporary negative technology shock with the same autoregressive structure as the net worth shock. This is presented in figures 9 and 10. The blue lines represent the net worth shock from the section 4.3. The red lines represent the technology shock. In the central case (the solid red lines), we calibrate this shock so that the initial impact on the price of capital Q is the same as under the net worth shock. We conduct a sensitivity analysis by increasing the size of the technology shock (the thin red lines).

Consider figure 9. It is clear from inspection that the technology shock has a smaller effect on the financial sector than the net worth shock. This is because the technology shock begins in the non-financial sector and the only way the non-financial sector affects the financial sector is through the return on the home asset. That is, the technology shock lowers the productivity of capital, which lowers the price of capital Q . This lowers the return on home assets R_E , which causes the bank to make a loss on its portfolio. Bank net worth thus falls and leverage rises. The way in which this increase in leverage

is transmitted to the other financial sector variables $(\bar{\omega}, \frac{R_{BANK}}{R}, E)$ is the same as under the bank net worth shock.

This shock, however, has a smaller effect on the banking sector for two reasons. First, the bank's portfolio is diversified. The bank also holds foreign assets. Second, the return on home assets recovers rapidly and is above its steady state level by the third quarter. The reason for this is that the price of capital Q is always rising on the adjustment path, which generates a capital gain on holding home assets. Thus the bank suffers a smaller fall in its net worth. As a result, its leverage position worsens by less and so the shock's effect on the financial sector is accordingly muted. We can see in the middle-left hand panel of figure 9 that the spread between bank return and riskless rates rises by less under the technology shock than under the net worth shock.

Because of this, the required adjustment of the exchange rate is much smaller. Hence, with a smaller cumulative per-period appreciation required along the adjustment path, the exchange rate experiences a smaller initial depreciation. The effect of the technology shock on the exchange rate is dampened, compared to the effect of the net worth shock²¹.

This is not simply an artefact of our parameterisation. We raise the size of this technology shock by 50% and 100% (the dashed and dotted thin red lines). In order to generate an increase in the spread of a similar size to that generated by the net worth shock, we would need an extremely large technology shock that causes output to fall

²¹To be explicit, recall equation (4)

$$\mathcal{E}_t \left(\frac{E_{t+1}}{E_t} \right) = \mathcal{E}_t \left(R_{BANK} \times \frac{1}{\text{spread}} \times \frac{1}{R^*} \right)$$

As the solid blue and solid red lines in figures 9 and 10 show, the fall in risky asset returns $R_{BANK} \downarrow$ is the same under both the net worth shock and the technology shock (which is unsurprising, because we set the size of both shocks to have the same effect on Q). However, the spread rises by more under the net worth shock $\frac{1}{\text{spread}} \downarrow\downarrow$ for the reasons described above, and so as (4) implies, the exchange rate adjustment under the net worth shock is greater $\frac{E_{t+1}}{E_t} \downarrow\downarrow$.

by an implausible $\sim 10\%$ on impact. And even in this case the exchange rate jump is still smaller than under the net worth shock.

Note, however, in figure 10, that the fall of output under the technology shock is larger than the fall under the net worth shock. This is because the technology shock begins in the non-financial sector and so has a more direct effect on output. On the other hand, the net worth shock only affects the non-financial sector indirectly by causing a fall in demand for capital goods. Hence, financial shocks have a greater effect on the financial sector and the exchange rate, but a smaller effect on the non-financial sector. Technology shocks exhibit the opposite effect. Household welfare is generally higher under the technology shock because consumption recovers more quickly (despite falling by more on impact).

4.6 Comparison with a model without financial frictions

In this section, we compare the technology shock of the previous section with the case where there are no financial frictions (we do not use a financial shock in this scenario because a financial shock in the absence of financial frictions would have no effect on the non-financial variables of the economy). This is implemented by setting the depositor monitoring cost μ to zero and setting the steady state spread between bank assets and the riskless rates to zero. The results are presented in figures 11 and 12.

Consider figure 11. In the case with no financial frictions, all the variables related to the loan contracts between banks and depositors do not move. This is because the bank's leverage position does not change. The bank's net worth falls due to the loss on the bank's portfolio and also due to the fall in the bank's labour income. However, this fall in bank net worth is matched by an equivalent fall in bank liabilities. The

bank becomes a frictionless intermediary in this version of the model. Hence the bank's leverage position does not change. Moreover, in the absence of financial frictions, the required spread between bank earnings and riskless rates does not exist in steady state and does not widen following a negative shock. Hence the burden of adjustment on the exchange rate is much smaller and so its volatility is accordingly muted. This is illustrated in the middle right-hand panel of figure 11.

To be explicit, recall equation (4)

$$\mathcal{E}_t\left(\frac{E_{t+1}}{E_t}\right) = \mathcal{E}_t\left(R_{BANK} \times \frac{1}{\text{spread}} \times \frac{1}{R^*}\right)$$

When the negative technology shock occurs: (i) bank asset returns fall $R_{BANK} \downarrow$ and (ii) banks thus make a loss, leading to a rise in leverage and thus the spread $\frac{1}{\text{spread}} \downarrow$. *Without the financial friction*, however, (i) the return on risky assets falls by less²² and (ii) there is no spread $\frac{1}{\text{spread}} \equiv 1$ and so, from (4), the short run burden of adjustment on the exchange rate is smaller. Financial frictions give rise to the risk premium (spread) that raises the volatility of the exchange rate and, furthermore, the larger the rise in the spread $\frac{1}{\text{spread}} \downarrow\downarrow$, the greater the short run burden of adjustment on the exchange rate (as shown by the comparison between technology and net worth shocks in the previous section - see footnote 21). Given the same long run level of the exchange rate, a greater short run adjustment then translates into a greater initial jump (recall Chapter 1).

Readers may notice that the “riskless” rate falls by more in the model without frictions. Hence they may expect that (since UIP holds) the exchange rate ought to depreciate by more in the model without frictions. This, however, is misleading. When there are no financial frictions, households invest directly in the home firm and so there is no longer a riskless rate. The deposit rate R is the same as the return on risky firm-issued

²²Due to well-understood financial accelerator effects (BGG; Kiyotaki and Moore, 1997)

assets R_E . Hence it is the *expectation of next period's return* that enters into the UIP condition (rather than the current realised known return, which can be discounted). In the model without frictions, after the shock, the expectation is that the return on assets recovers very quickly and so the required exchange rate adjustment is accordingly muted.

Consider the non-financial sector in figure 12. As expected, the responses of variables are larger in the model with financial frictions. This is because of the well-understood effects of the financial accelerator on the closed-economy business cycle (BGG; Kiyotaki and Moore, 1997). In the presence of financial frictions, the risk premium gives rise to a feedback loop that causes demand for capital goods to decrease by more. Hence the price of capital falls by more and so the responses of investment, labour supply, and output are augmented in the presence of financial frictions.

For the purpose of continuity with the the other Chapters (where permanent productivity shocks are discussed), we also present simulations of a permanent 1% fall in technology. These are presented in figures 13 and 14. The interpretations for these simulations are identical to those given above for the temporary shocks. Adding financial frictions increases the volatility of the exchange rate for the same reasons given above. (The responses here are much smaller because the size of the permanent shock itself is small. This is deliberately set so as to ensure the results remain accurate.)

This concludes the discussion of specific simulations. In the next section, we synthesise the main results from this Chapter.

Figure 5: Simulation of a bank net worth shock (1 of 2)

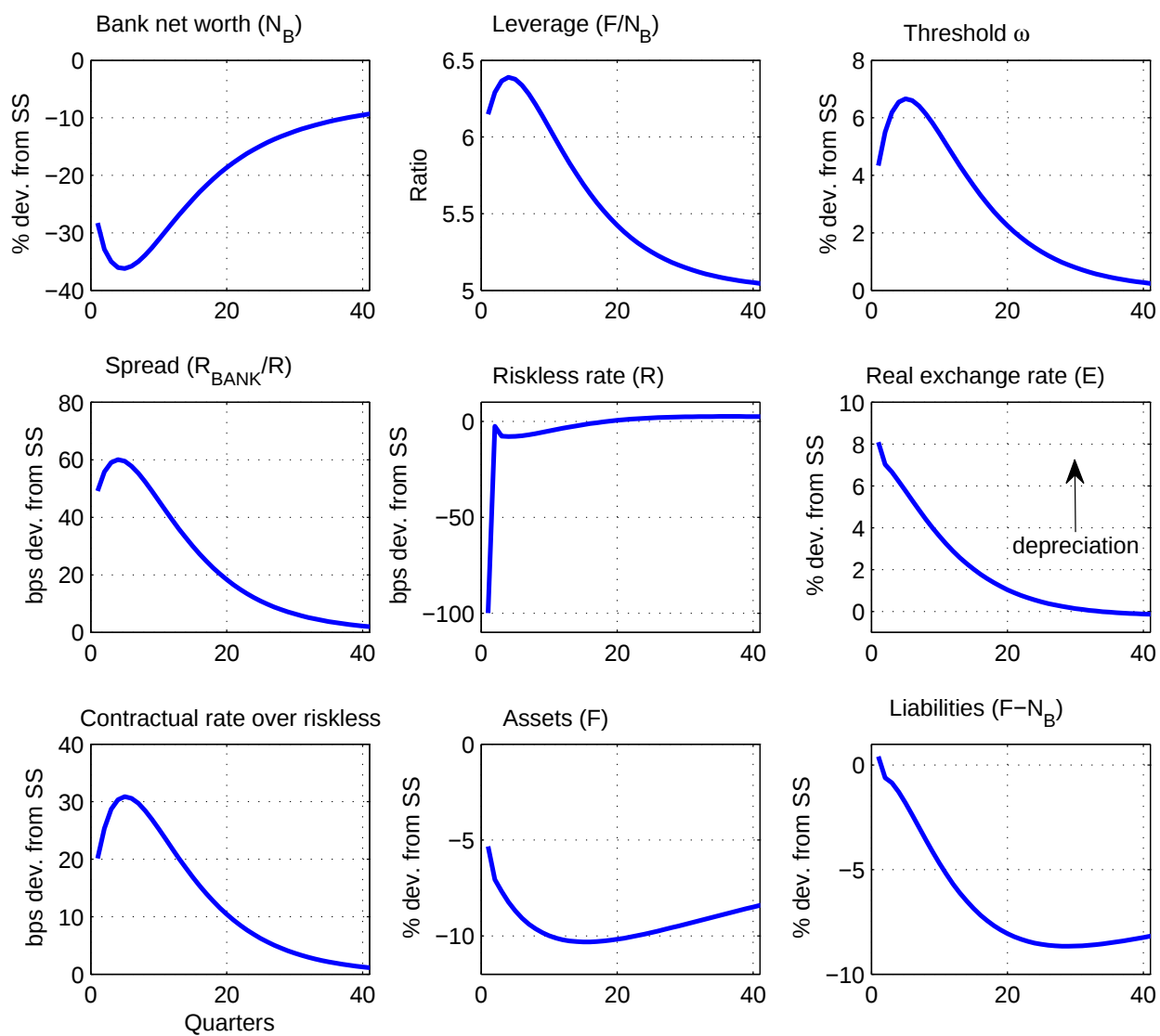


Figure 6: Simulation of a bank net worth shock (2 of 2)

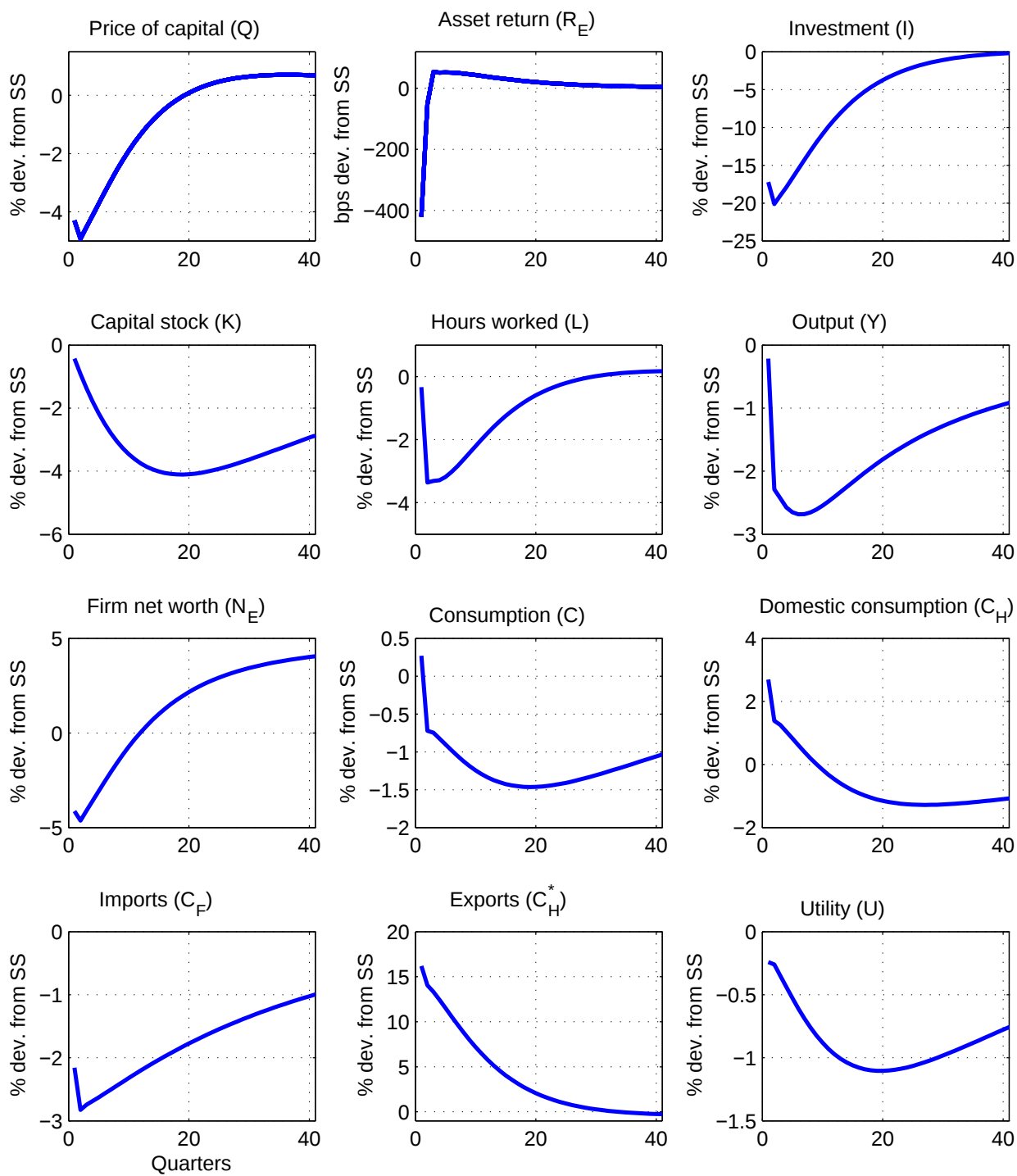


Figure 7: Different degrees of currency mismatch (1 of 2)

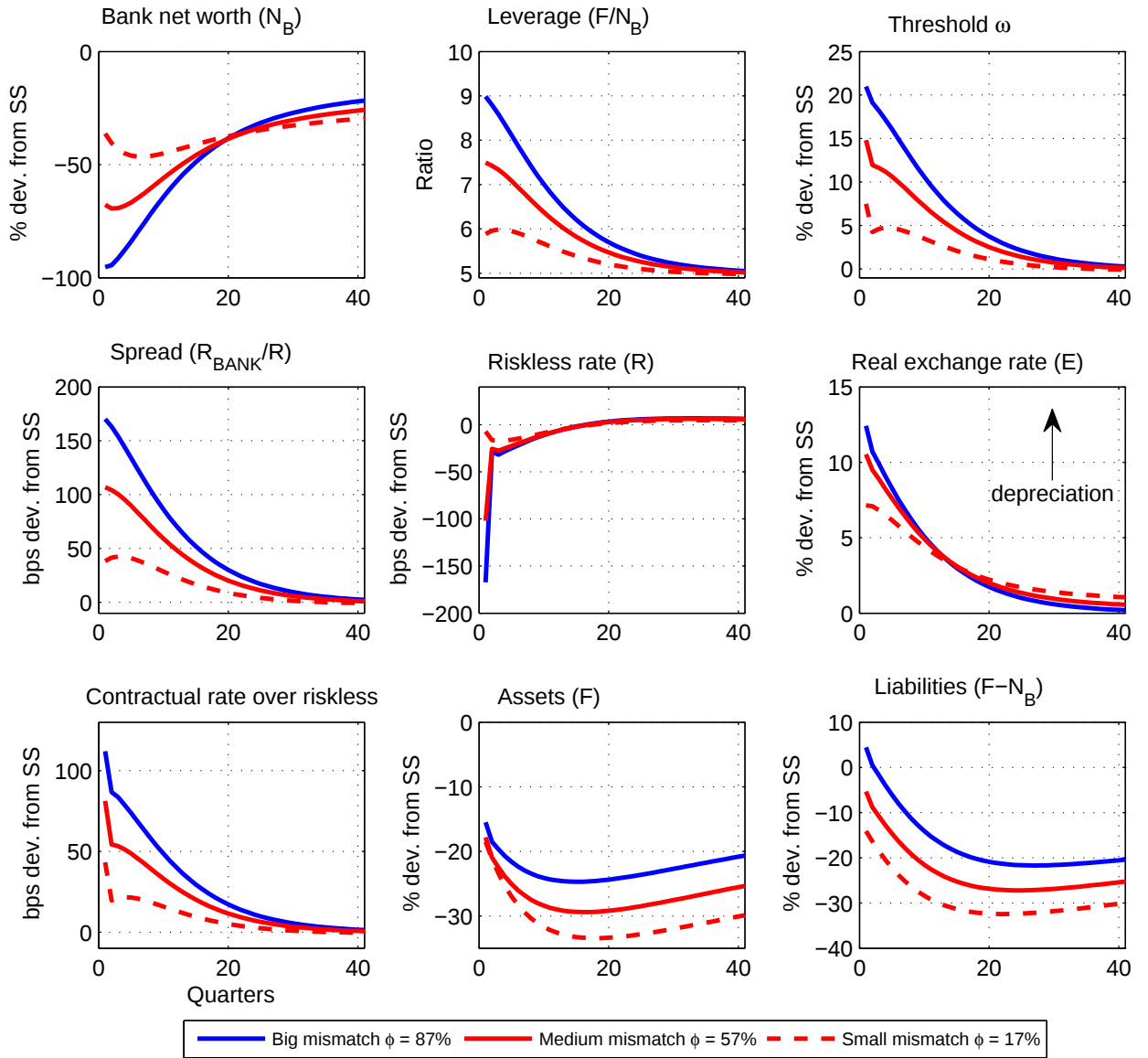


Figure 8: Different degrees of currency mismatch (2 of 2)

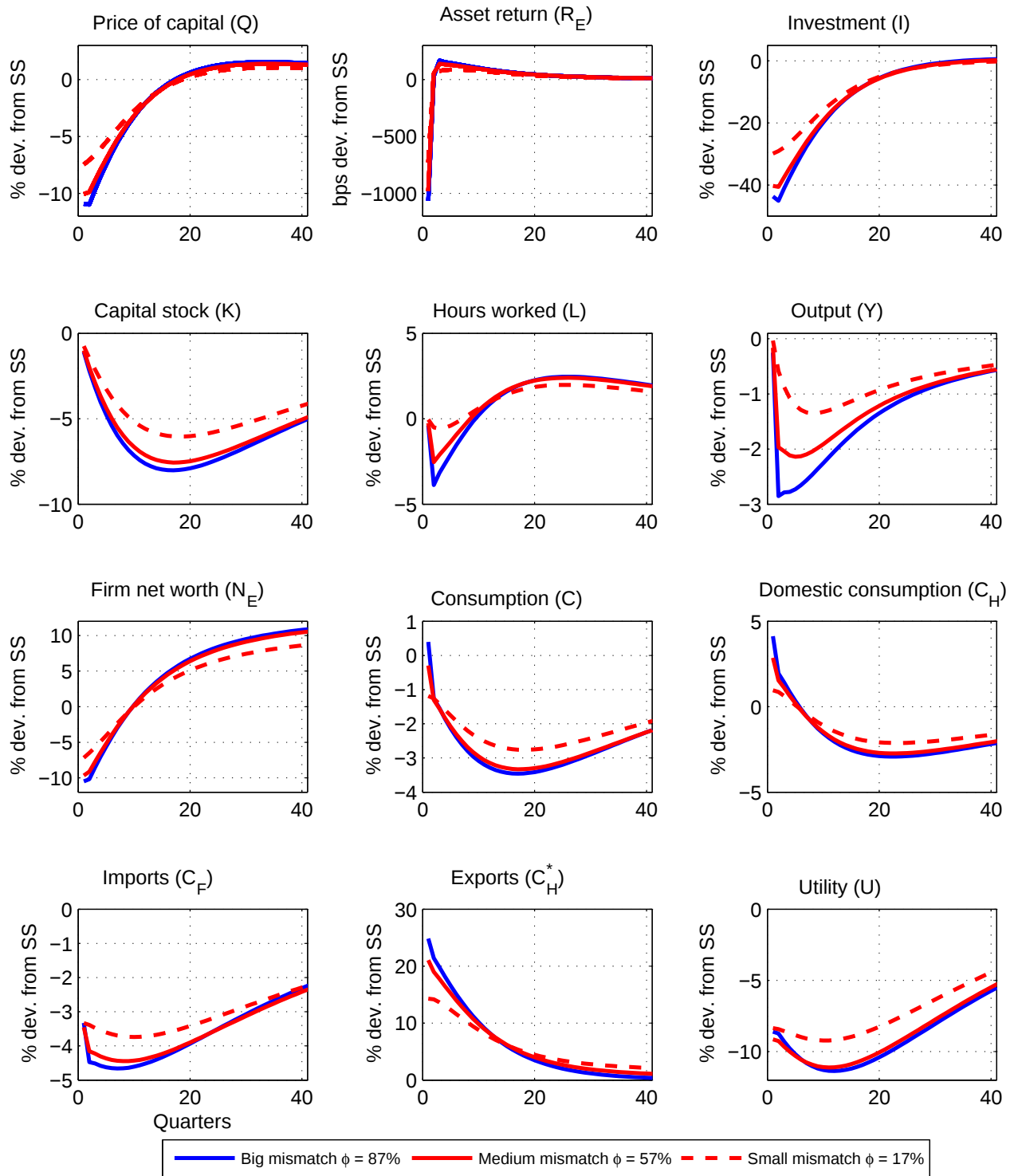


Figure 9: Comparison with a technology shock (1 of 2)

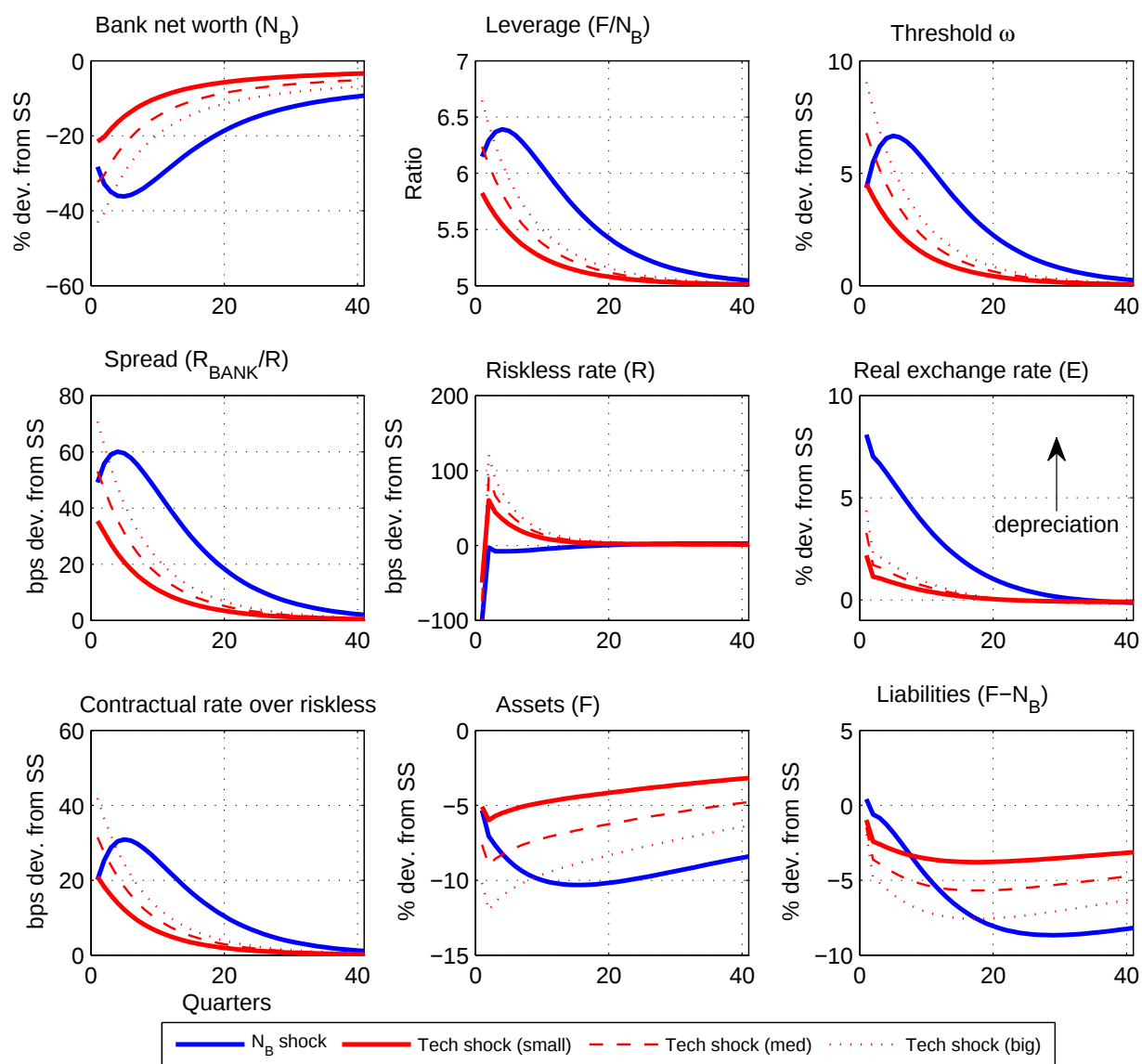


Figure 10: Comparison with a technology shock (2 of 2)

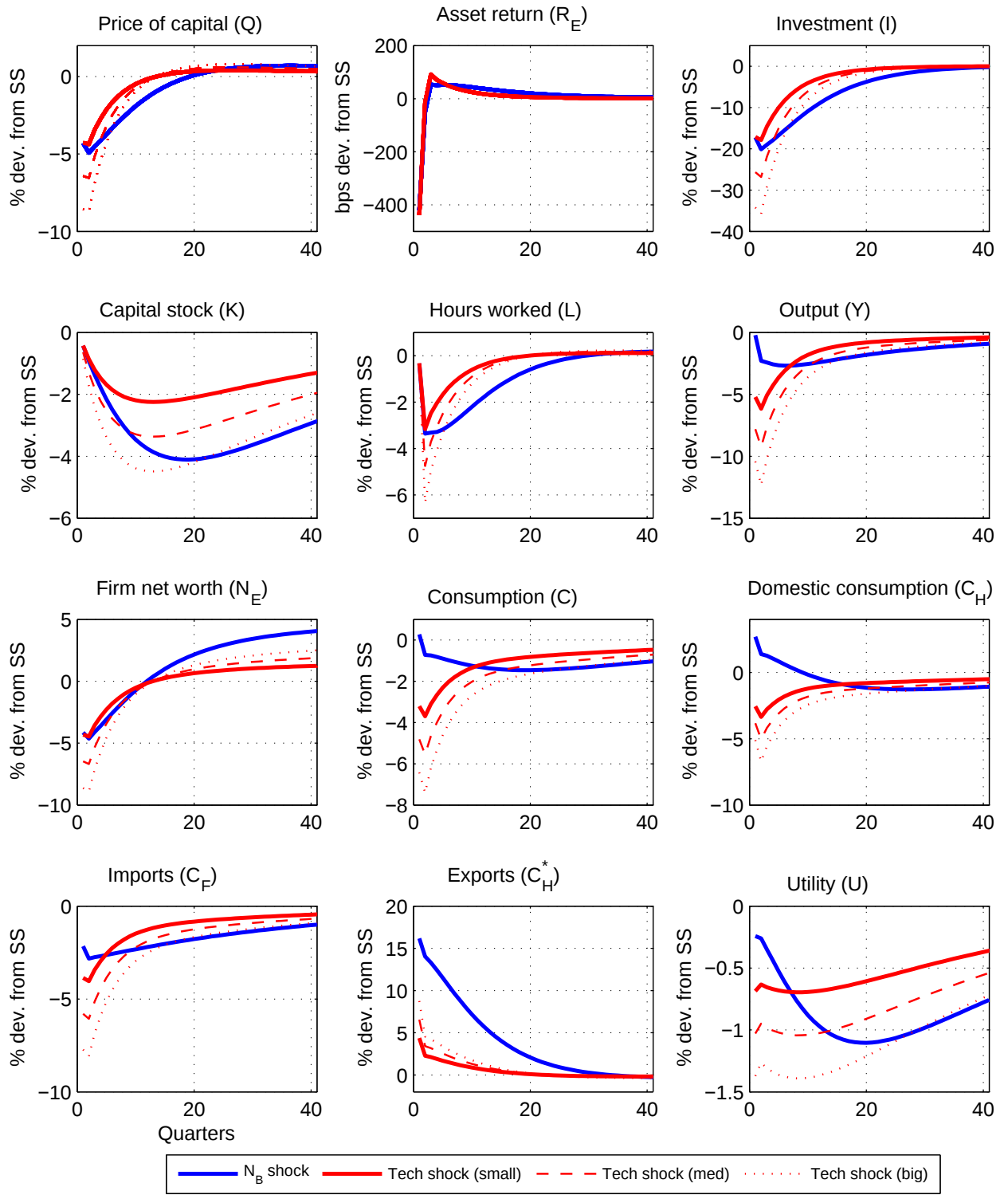


Figure 11: Comparison with no financial frictions (1 of 2)

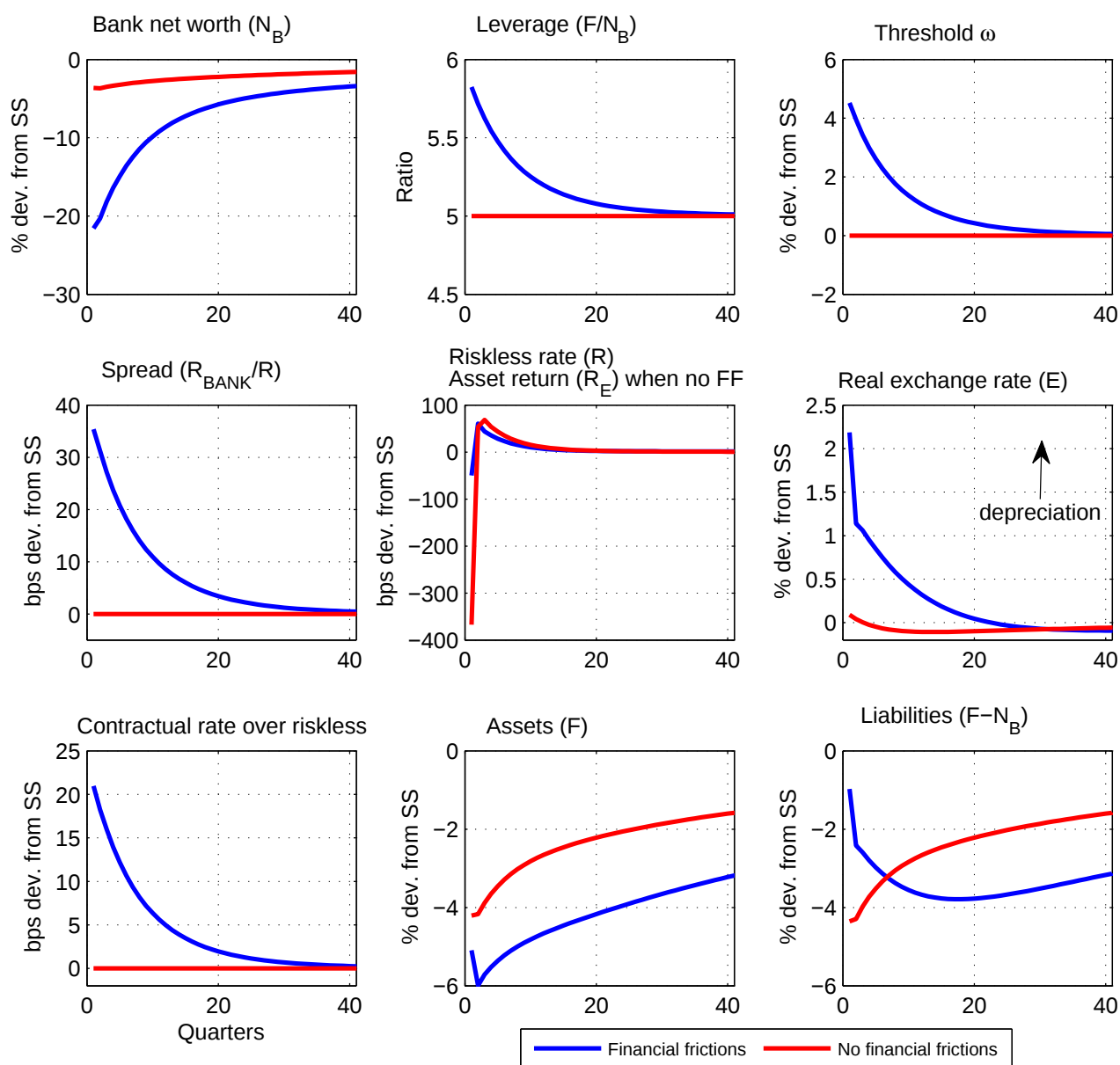


Figure 12: Comparison with no financial frictions (2 of 2)

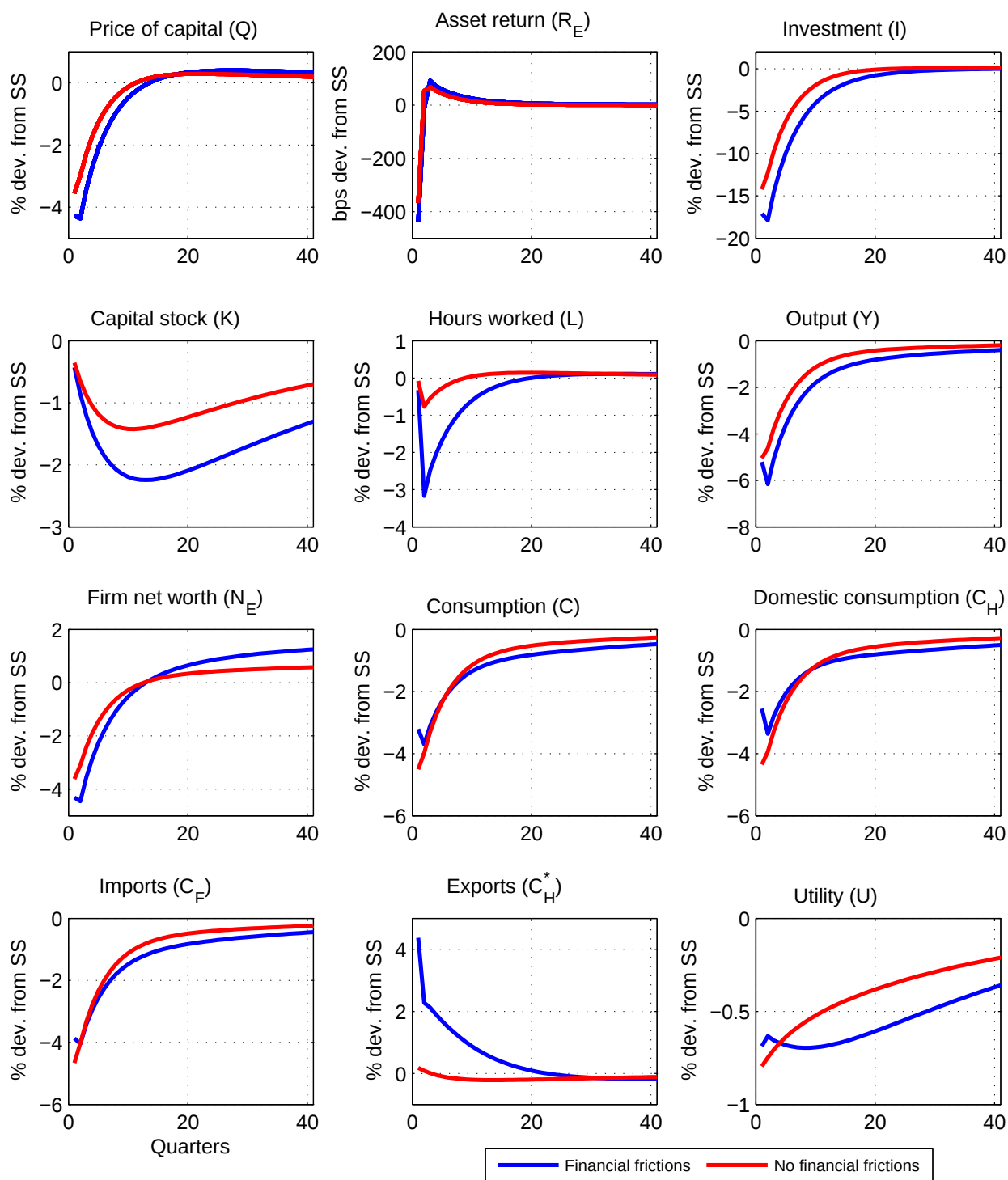


Figure 13: Comparison with no financial frictions - permanent shock (1 of 2)

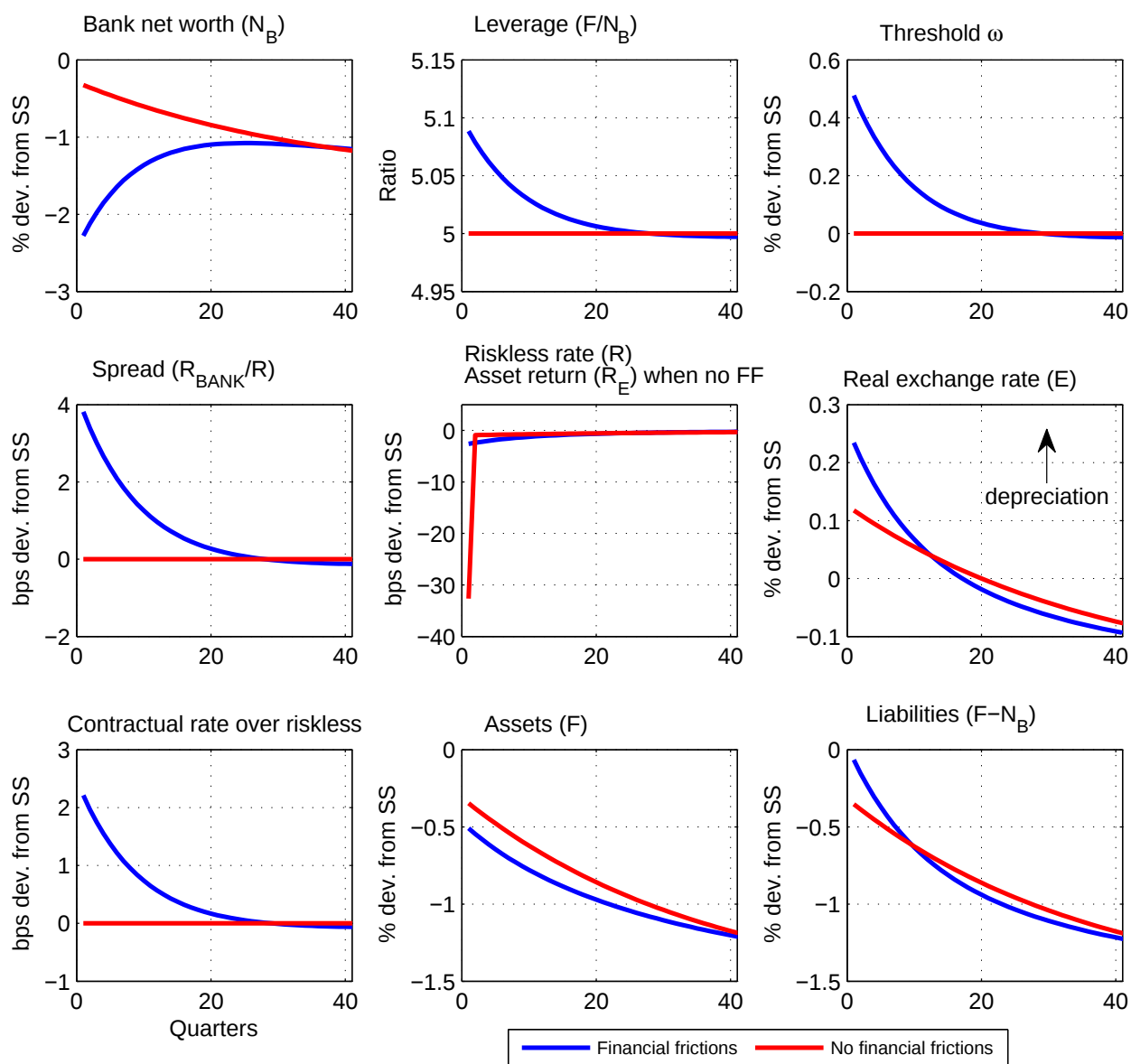
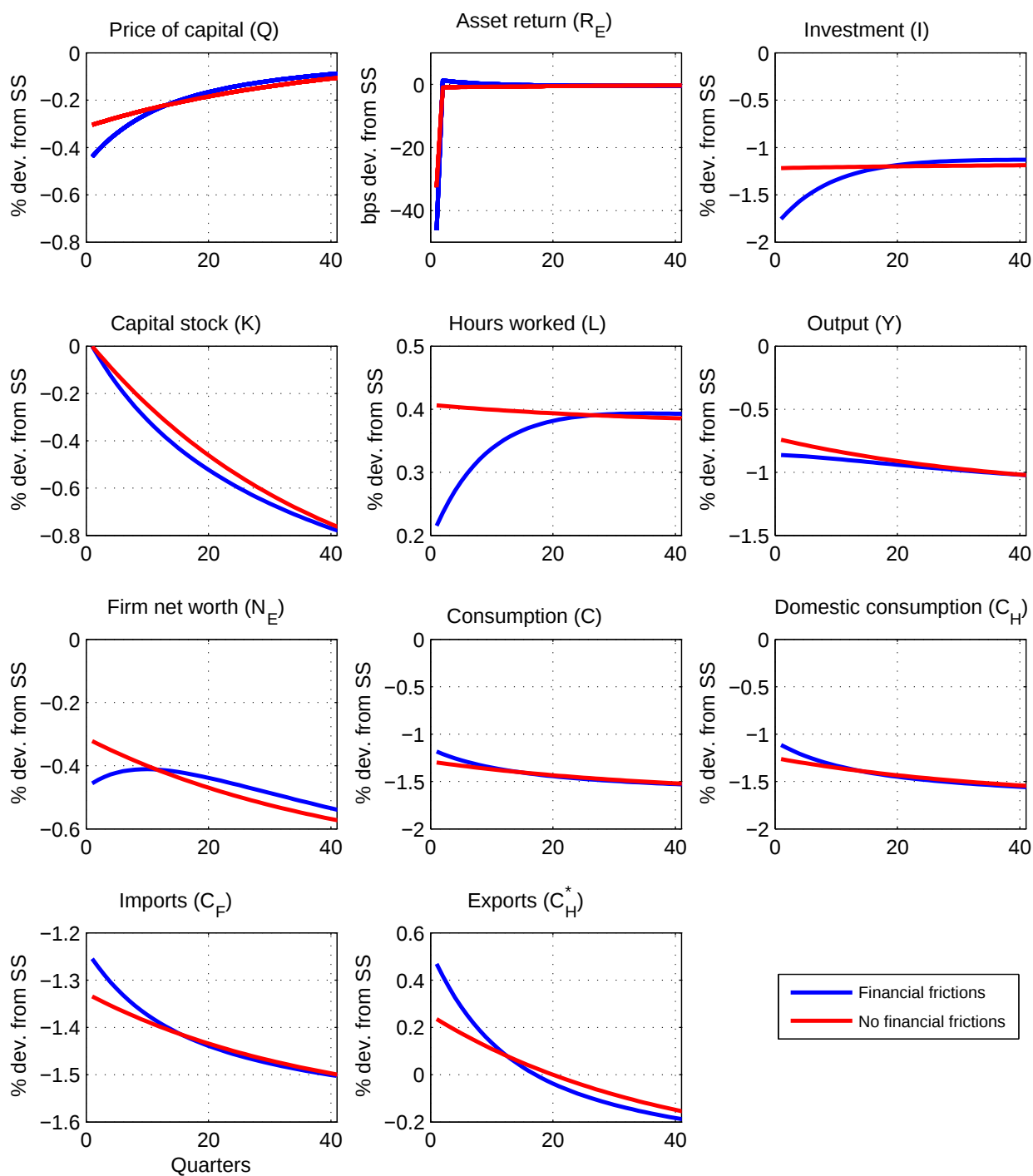


Figure 14: Comparison with no financial frictions - permanent shock (2 of 2)



5 Discussion

5.1 Summary of results

In this section, we summarise the results of this Chapter and discuss some implications of these results.

The main results are

1. Financial frictions increase the volatility of the exchange rate. This is because financial frictions give rise to risk premia that further widen after negative shocks. This raises the burden of adjustment on the exchange rate along the short run path, which augments the size of exchange rate jumps after shocks. Figure 11 shows that removing financial frictions dampens the effect of shocks on the exchange rate (recall equation (4)). Furthermore, figure 7 shows that a larger jump in the risk premium leads to a larger initial depreciation of the exchange rate. The channel through which the risk premium affects the exchange rate is discussed at length in sections 4.2 and 4.3.
2. A financial shock can lead to a large fall in exchange rates even without a currency mismatch, as shown in figure 5. This is because spikes in risk premia can occur regardless of the composition of balance sheets. As long as depositors are able to divert their funding abroad, the bank will have to earn a higher spread above the foreign riskless rate if bank leverage worsens. However, as figure 7 shows, lowering the currency mismatch does dampen the effect of the financial shock on the exchange rate. With a smaller mismatch, banks effectively hedge against denomination risk and so make a smaller loss when measured in terms of the foreign good. So, decreasing the mismatch lowers the required exchange rate

adjustment. In short, the currency mismatch can affect the volatility of the exchange rate (as in the standard currency crisis literature, e.g. Aghion *et al.* and Cespedes *et al.*), but financial shocks can lead to large falls in exchange rates for other reasons independent of the mismatch. This is significant because currency mismatches on balance sheets are typically small (Bleakley and Cowan, 2008). (In Appendix 2, we use the method of Devereux and Sutherland [2011] to solve for the optimal steady state portfolio of the bank and show that this model also predicts that banks minimise the mismatch on their balance sheets.)

3. Financial shocks have a greater effect on exchange rates than technology shocks (conditional on the shocks having similar-sized effects on other variables). This is shown in figures 9 and 10. This is because technology shocks lead to a smaller rise in the risk premium and hence the required adjustment of the exchange rate is also smaller.

The first result above extends to the open economy and to the exchange rate the well-known result (Kiyotaki and Moore 1997; Bernanke, Gertler and Gilchrist 1999; Gertler, Gilchrist and Natalucci 2007; Gertler and Kiyotaki 2010) that financial frictions increase volatility in the closed economy. We provide an explicit treatment of the effect of financial frictions and risk premia on exchange rate adjustment, something that is not directly addressed by canonical work on financial frictions in open economies (e.g. Gertler, Gilchrist and Natalucci, 2007; and Claus, 2011). This finding is consistent with the results of an extensive empirical literature (e.g. Elekdag *et al.*; Li *et al.*; MacDonald and Torrance, 1989; Taylor, 1989; Cavaglia, Verschoor and Wolff, 1993) that balance sheet vulnerabilities and risk premia are important for explaining fluctuations of the exchange rate.

5.2 Other types of financial frictions

In this Chapter, we have employed a specific financial friction, the BGG financial accelerator framework. There are other types of frictions, the most prominent being the moral hazard friction employed by Gertler and Karadi (2011) and Gertler and Kiyotaki (2010). It can be shown that the results from this Chapter go through if we adopt these other financial frictions. The key fact about financial frictions in general is that they generate a non-negative spread between the return on risky assets and riskless rates. This spread, furthermore, is an increasing function of bank (or firm, depending on who is the borrower in the financial friction) leverage. Hence, under any general type of financial friction, a worsening of bank leverage would lead to a widening of risk premia, which would raise the burden of adjustment on the exchange rate.

For concreteness, consider a stylised version of the Gertler and Kiyotaki (2010) (moral hazard) friction. This is based loosely around Cespedes, Chang, and Velasco (2012). Suppose that banks supply quantity F of financial intermediation for a risky return of R^B . Banks have net worth N_B and borrow quantity D of foreign goods from foreign depositors at a cost of R^* . Hence, for an exchange rate E

$$F_t = N_{Bt} + D_t E_t \quad (32)$$

Next period, when shocks are realised, the bank's profit is

$$F_t R_{t+1}^B - D_t E_{t+1} R_{t+1}^* = F_t R_{t+1}^B - R_{t+1}^* \frac{E_{t+1}}{E_t} (F_t - N_{Bt})$$

where the expression on the right-hand side arises from substituting in equation (32). Bank borrowing is subject to a collateral constraint which imposes the condition that bank net profit must be at least as great as some proportion $\mu \in (0, 1)$ of bank gross

income

$$F_t R_{t+1}^B - D_t E_{t+1} R_{t+1}^* \geq \mu F_t R_{t+1}^B \quad (33)$$

(33) is motivated by supposing that the bank can declare default and abscond with proportion μ of its total gross income. The constraint in (33) ensures that this default event does not occur. If the constraint (33) holds with equality (that is, the financial friction is binding), then in equilibrium, we can show (by combining (32) and (33)) that there is a positive spread between the return on bank assets and the foreign riskless rate

$$\frac{R_{t+1}^B}{R_{t+1}^* E_{t+1}/E_t} = \frac{D_t E_t / N_{Bt}}{(1 - \mu)(1 + D_t E_t / N_{Bt})} \quad (34)$$

This spread exists because of the possibility that the bank can abscond with a fraction of the bank income. The constraint (33) requires that banks earn a higher return relative to riskless rates, therefore ensuring that bank net profit is so high that there is no incentive to abscond. We can interpret this spread as the compensation that depositors demand for the risk of absconding.

Finally, note that this spread in (34) is an increasing function of the bank's leverage $D_t E_t / N_{Bt}$ ²³. This means that the results from this Chapter go through if we adopt this type of financial friction²⁴. A worsening of bank leverage will require that the spread

²³It can be shown that $\frac{d\left(\frac{R_{t+1}^B}{R_{t+1}^* E_{t+1}/E_t}\right)}{d(D_t E_t / N_{Bt})} = \frac{1}{(1-\mu)(1+D_t E_t / N_{Bt})^2} > 0$.

²⁴There are two more types of well-known financial frictions. (i) In the unobserved effort model (e.g. Christiano and Ikeda, 2012), depositors cannot observe the effort with which bankers intermediate funds between them and investment projects. Because of this, depositors demand a spread between the bank earnings and deposit rates. (ii) In the adverse selection model (e.g. Mankiw, 1986), depositors cannot distinguish between “good” and “bad” banks and therefore banks must all pay the same rate of return to depositors which must be high enough to take into account the “bad” banks with high riskiness, leading to a risk spread over deposit rates. Hence, in all main financial frictions models, this risk spread exists as a positive function of borrower leverage.

increase $\frac{R_{t+1}}{R_{t+1}^* E_{t+1}/E_t} \uparrow$, and if the foreign riskless rate R^* does not adjust, then it is the exchange rate that must appreciate $\frac{E_{t+1}}{E_t} \downarrow$. A large cumulative per-period appreciation then implies a large initial depreciation after the shock.

In Appendix 3, we develop a two-period model that employs this moral hazard financial friction. We show in this Appendix that the same results as in this Chapter go through. Moreover, in the next Chapter, we build a full multi-period general equilibrium model using this friction and we show that the same results as in this Chapter obtain.

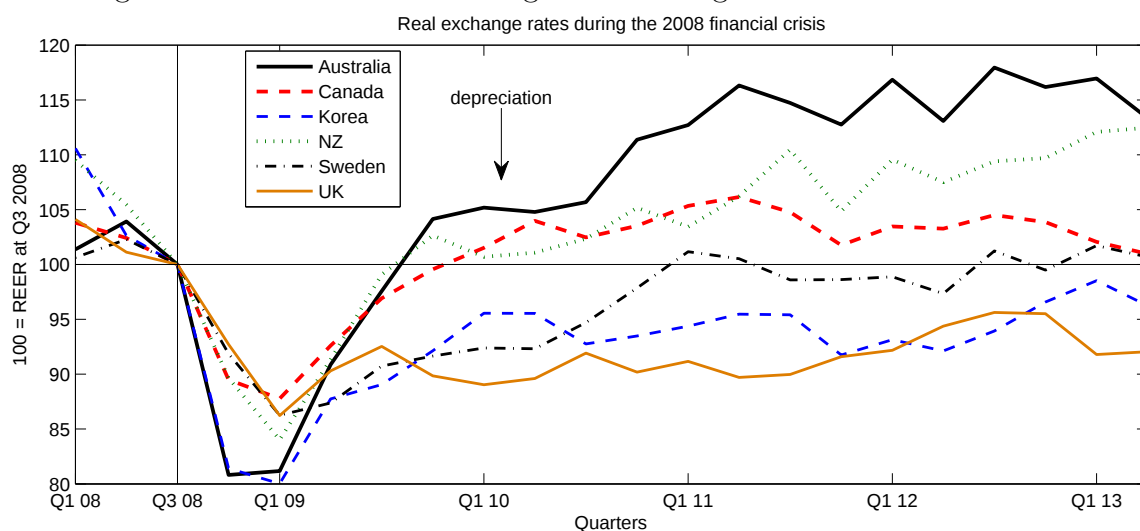
5.3 The 2008 crisis in perspective

Before we conclude this Chapter, we look at what insight this Chapter can provide into an actual instance of a financial shock. Consider the financial panic of 2008. While other factors such as extraordinary monetary policy will of course explain a large portion of exchange rate movements in that period, the narrative of this Chapter may be able to offer an additional (and complementary) explanation. Figure 15 shows that: (i) when the crisis hit in the third quarter of 2008, exchange rates depreciated rapidly; (ii) exchange rates recover immediately afterwards and some surpass their initial levels several periods after the fall. Australia's REER, for instance, depreciated by nearly 20% in the space of one quarter but had appreciated by 5%, relative to its starting point, by the fifth quarter after the shock.

First we describe the context of the crisis. The 2008 panic was characterised by two inter-related problems. First, banks had suffered capital losses due to a run on real estate-related securities. Hence banks that had no direct dealings with US subprime markets nonetheless realised large losses²⁵. Second, interbank liquidity collapsed. This

²⁵E.g. In 2007, RBS suffered a write-down of its subprime assets of £2 billion, an amount equivalent to over a quarter of the bank's net profit that year (RBS 2007 Annual Report).

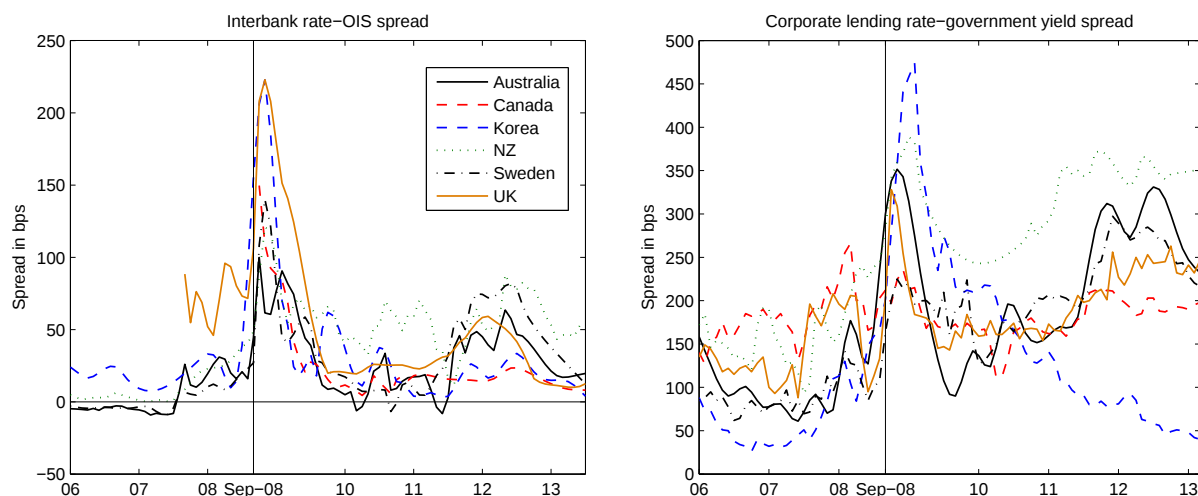
Figure 15: Real effective exchange rates during the 2008 financial crisis



is related to the first problem since we would expect banks not to lend to other banks that had stressed balance sheets and high counterparty risk. As a result, interbank risk premia spiked (left-panel figure 16) as lenders hoarded liquidity and demanded greater compensation for providing funds to a vulnerable banking system. This panic has been interpreted as a standard bank run, but instead of the withdrawal of consumer deposits, it was the withdrawal of repo lending that caused money markets to freeze (e.g. Gorton and Metrick 2012). Because interbank lenders demanded higher risk premia from banks, banks then had to earn higher spreads on their assets to meet these higher premia. This is why in subsequent periods, the spreads on corporate lending rates above riskless rates also spiked (right-panel figure 16). Capital flooded away from risky assets to riskless assets (sovereign debt), pushing down government yields and opening up this spread.

On first inspection, it appears that the narrative of this Chapter offers some plausible insights into the 2008 crisis. The expectation of losses on subprime assets worsened bank leverage. Liquidity in interbank markets froze. Risk premia spiked. The exchange rate thus had to appreciate in order for banks to earn required spreads. In effect, a flight to safety occurred as capital flooded to safe-haven government bonds at home and

Figure 16: Risk premia during the financial crisis



Interbank spread = 3-month interbank rate spread over 3-month OIS for Aus, Can, UK; otherwise 1-yr interbank rate spread over 1-yr swap rate. Corporate lending rate = prime lending rate or equivalent. Govt yield = secondary market yield on 1-year government bond

abroad. This pushed down riskless rates and caused currencies to depreciate until they were sufficiently under-valued to entice creditors to remain in domestic money markets.

There is some tentative evidence to connect our narrative to 2008. Li, Ghoshray and Morley (2012) find that for some of the countries in figure 15 (UK, Australia, Canada), the sharp jumps in the exchange rates in 2008 coincide with sharp spikes in the permanent component in the risk premium (suggesting an increase in the riskiness of fundamentals rather than simply a change in market sentiment). Conversely, the exchange rates of countries like Thailand and Switzerland, whose measures of risk did not rise sharply in 2008, only reacted mildly to the crisis²⁶.

Of course we do not claim that this Chapter explains exchange rates in 2008 *entirely*. Clearly, monetary policy played a significant role in 2008. During this period, central banks were easing aggressively, which caused short-term interest rates to plummet.

²⁶In real trade-weighted terms, the Swiss franc and Thai baht moved by no more than 3% in the months around Q3 2008 (BIS).

However, the central banks of almost all major economies were easing, which casts some doubt as to whether monetary policy is the *only* driver of these movements. We find it encouraging that while the Federal Reserve was easing more aggressively than the central banks of any of the countries considered in figure 15 (in terms of the proportional change in official rates), the US dollar appreciated sharply. This suggests that flight-to-safety effects were dominant, as investors flowed out of foreign money markets towards safe-haven US assets, which is consistent with our narrative. There is thus “room” for our additional proposed narrative.

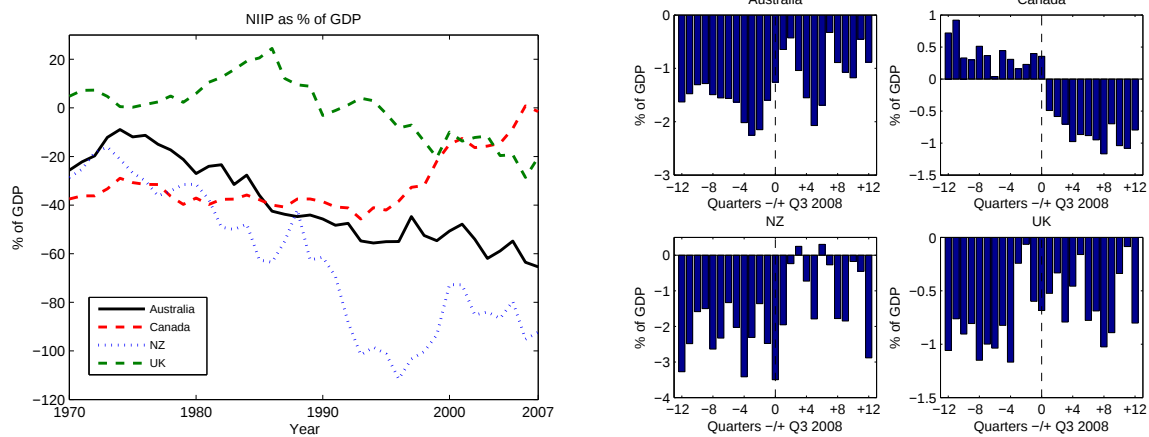
Another caveat is that the behaviour of the Australian and Canadian dollars may overstate our case because of the distortionary effects of commodities demand. However, non-commodities-related currencies such as the South Korean won and the Swedish krona also behaved in the same way. We can reasonably rule out another possible narrative, that of a standard balance of payments crisis (i.e. a sudden stop of foreign capital). While some of these countries did exhibit growing foreign debt up to 2008, the levels of net foreign debt were not excessive and there is no obvious common pattern (figure 17). Certainly, the current accounts do not swing from deficit into surplus following the shock, as would be expected in a balance of payments crisis (see figure 11 in Chapter 2) and countries had no obvious problems funding sizeable current account deficits post-crisis (most notably, the UK).

6 Concluding remarks

Having summarised the Chapter’s results in the previous section 5.1, we conclude by noting some caveats and possible extensions.

First, the analysis in this paper relies on the assumption that the world interest rate

Figure 17: Balance of payments before and after the crisis



Source: Lane & Milesi-Ferretti (2007), World Bank JEDH, IMF IFS, & own calculations

does not change significantly after the shock to home net worth. This simplifies the analysis because it places all the burden of adjustment on the exchange rate, rather than the foreign interest rate. This would plausibly fit a situation in which the crisis is confined to the domestic country. However, the 2008 crisis was global in nature and interest rates were affected in most countries. It would be more realistic to nest the system in a two-country model with a small country representing home and a large country representing the rest of the world. This would endogenise developments largely treated as *ad hoc* in this Chapter.

Second, the fall in global interest rates was a function of lower expected growth and lower investment due to macroeconomic uncertainty. However, it also reflected the extraordinary monetary policy action taken in 2008 and 2009 to counter the effects of the financial crisis. Another possible extension to our model, then, would be to explicitly examine the behaviour of exchange rates during a financial crisis in the presence of unconventional monetary policy.

Table 2: External debt and asset positions before the crisis

A. External debt (% of GDP)

	2000	2001	2002	2003	2004	2005	2006	2007
Australia	109.91	117.86	124.29	140.45	138.87	124.98	150.79	161.73
Canada	108.33	108.29	110.32	112.49	110.44	103.36	106.46	110.60
NZ	139.75	138.17	158.05	154.76	152.87	135.27	163.75	162.72
UK	305.34	319.23	316.62	343.15	362.88	382.05	448.49	476.46

Source: World Bank, Lane & Milesi-Ferretti (2007), & own calculations

B. External assets (% of GDP)

	2000	2001	2002	2003	2004	2005	2006	2007
Australia	59.23	70.02	70.25	78.52	79.99	70.19	87.24	96.34
Canada	93.36	95.71	93.99	96.77	95.87	94.87	104.29	109.09
NZ	67.07	65.38	72.82	70.81	66.23	55.66	68.60	70.43
UK	295.37	305.56	304.42	331.54	343.28	362.79	419.89	456.11

Source: World Bank, Lane & Milesi-Ferretti (2007), & own calculations

C. Bank foreign currency liabilities (% of total liabilities)

	2000	2001	2002	2003	2004	2005	2006	2007
Australia	19.48	21.88	19.43	18.09	19.46	20.38	20.12	19.73
UK	25.09	27.72	29.51	31.22	31.48	33.86	33.25	37.44

Source: national central banks & own calculations

D. Bank foreign currency assets (% of total assets)

	2000	2001	2002	2003	2004	2005	2006	2007
Australia	9.17	9.78	9.96	9.42	11.01	10.78	10.84	11.75
UK	24.02	26.88	27.88	29.33	30.54	33.86	33.01	36.74

Source: national central banks & own calculations

References

- [1] Adolfson, Malin, Stefan Laseen, Jesper Linde & Mattias Villani. 2005. Bayesian estimation of an open economy DSGE model with incomplete pass-through. Working Paper Series no. 179. Sveriges Riksbank.
- [2] Aghion, Philippe, Philippe Bacchetta, & Abhijit Banerjee. 2004. A corporate balance-sheet approach to currency crises. *Journal of Economic Theory* 119 (1): 6—30.
- [3] Allen, David E. & Robert Powell. 2012. The fluctuating default risk of Australian banks. *Australian Journal of Management* 37 (2): 297—325.
- [4] Amano, Robert & Malik Shukayev. 2012. Risk premium shocks and the zero bound on nominal interest rates. *Journal of Money, Credit and Banking* 44 (8): 1475—1505.
- [5] Anker, Peter. 1999. Uncovered interest parity, monetary policy and time-varying risk premia. *Journal of International Money and Finance* 18 (1999): 835—51.
- [6] Bernanke, Ben S., Mark Gertler & Simon Gilchrist. 1999. The financial accelerator in a quantitative business cycle framework. In *Handbook of Macroeconomics* 1 (1), edited by John B. Taylor & Michael Woodford. Elsevier.
- [7] Blanchard, Olivier & Jordi Gali. 2010. Labour markets and monetary policy: a new Keynesian model with unemployment. *American Economic Journal: Macroeconomics* 2 (2): 1—30.
- [8] Bleakley, Hoyt & Kevin Cowan. 2008. Corporate dollar debt and depreciations: much ado about nothing?. *The Review of Economics and Statistics* 90 (4): 612—626.
- [9] Cappiello, Lorenzo & Roberto A. De Santis. 2005. Explaining exchange rate dynamics - the uncovered equity return parity condition. ECB Working Paper Series 529. European Central Bank.
- [10] Carranza, Luis, Jose E. Galdon-Sanchez, & Javier Gomez-Biscarri. 2011. The relationship between investment and large exchange rate depreciations in dollarized economies. *Journal of International Money and Finance* 30 (7): 1265—79.
- [11] Cavaglia, Stefano, Willem Verschoor & Christian Wolff. 1993. Further evidence on exchange rate expectations. *Journal of International Money and Finance* 12 (1): 78—98.
- [12] Cespedes, Luis F., Roberto Chang, & Andres Velasco. 2004. Balance sheets and exchange rate policy. *American Economic Review* 94 (4): 1183—93.

- [13] ———. 2012. Financial intermediation, exchange rates, and unconventional policy in an open economy. NBER Working Papers 18431. National Bureau of Economic Research.
- [14] Chari, Varadarajan V., Patrick J. Kehoe, & Ellen R. McGrattan. 2005. Sudden stops and output drops. *American Economic Review* 95 (2): 381—387.
- [15] Christiano, Lawrence J. & Daisuke Ikeda. 2012. Government policy, credit markets and economic activity. NBER Working Papers 17142, National Bureau of Economic Research.
- [16] Claus, Iris. 2007. The effects of bank lending in an open economy. *Journal of Money, Credit and Banking* 39 (5): 1213—48.
- [17] ———. 2011. The effects of asymmetric information between borrowers and lenders in an open economy. *Journal of International Money and Finance* 30 (5): 796—816.
- [18] Craig, Ben & Valeriya Dinger. 2010. A microeconomic investigation into bank interest rate rigidity. Working Paper 10-01. Federal Reserve Bank of Cleveland.
- [19] ———. 2013. Uncertainty and bank wholesale funding. Discussion Paper No. 39/2013. Deutsche Bundesbank.
- [20] Devereux, Michael B., & Alan Sutherland. 2011. Country portfolios in open economy macro-models. *Journal of the European Economic Association* 9 (2): 337—69.
- [21] Dinger, Valeriya. 2011. Bank mergers and deposit interest rate rigidity. Working Paper 11-31. Federal Reserve Bank of Cleveland.
- [22] Elekdag, Selim, Alejandra Justiniano & Ivan Tchakarov. 2006. An estimated small open economy model of the financial accelerator. *IMF Staff Papers* 53 (2): 2.
- [23] Engel, Charles & Akito Matsumoto. 2009. The international diversification puzzle when goods prices are sticky: it's really about exchange-rate hedging, not equity portfolios. *American Economic Journal: Macroeconomics* 1 (2): 155—88.
- [24] Fama, Eugene F. 1984. Forward and spot exchange rates. *Journal of Monetary Economics* 14: 319—38.
- [25] Gali, Jordi & Tommaso Monacelli. 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies* 72: 707—34.
- [26] Gertler, Mark, Simon Gilchrist & Fabio Natalucci. 2007. External constraints on monetary policy and the financial accelerator. *Journal of Money, Credit and Banking* 39 (2—3): 295—330.

-
- [27] Gertler, Mark & Peter Karadi. 2011. A model of unconventional monetary policy. *Journal of Monetary Economics* 58 (1): 17—34.
- [28] Gertler, Mark & Nobuhiro Kiyotaki. 2010. Financial intermediation and credit policy in business cycle analysis. In *Handbook of Monetary Economics* 3 (chapter 11), first edition, edited by Benjamin M. Friedman & Michael Woodford. Elsevier.
- [29] Gilchrist, Simon & John V. Leahy. 2002. Monetary policy and asset prices. *Journal of Monetary Economics* 49 (1): 75—97.
- [30] Gorton, Gary B. & Andrew Metrick. 2012. Securitized banking and the run on repo. *Journal of Financial Economics* 104 (3): 425—51.
- [31] Hirakata, Naohisa, Nao Sudo & Kozo Ueda. 2011. Do banking shocks matter for the US economy?. *Journal of Economic Dynamics and Control* 35 (12): 2042—63.
- [32] Hodge, Andrew, Tim Robinson & Roby Stuart. 2008. A small BVAR-DSGE model for forecasting the Australian economy. *RBA Research Discussion Papers* rdp 2008-04, Reserve Bank of Australia.
- [33] Kiyotaki, Nobuhiro & John Moore. 1997. Credit cycles. *Journal of Political Economy* 105 (2): 211—48.
- [34] Krugman, Paul. 1999. Balance sheets, the transfer problem, and financial crises. *International Tax and Public Finance* 6 (4): 459—72.
- [35] Lane, Philip R. & Gian Maria Milesi-Ferretti. 2007. The external wealth of nations mark II: revised and extended estimates of foreign assets and liabilities, 1970-2004. *Journal of International Economics* 73 (2): 223—50.
- [36] Lees, Kirdan, Troy Matheson & Christie Smith. 2007. Open economy DSGE-VAR forecasting and policy analysis: head to head with the RBNZ published forecasts. RBNZ Discussion Paper Series DP2007/01. Reserve Bank of New Zealand.
- [37] Li, Dandan, Atanu Ghoshray, & Bruce Morley. 2012. Measuring the risk premium in uncovered interest parity using the component GARCH-M model. *International Review of Economics and Finance* 24 (2012): 167—176.
- [38] Luk, Sheung Kan & David Vines. 2011. Financial-friction macroeconomics with highly leveraged financial institutions. CEPR Discussion Papers 8576. Centre for Economic Policy Research.
- [39] MacDonald, Ronald & Thomas S. Torrance. 1989. Some survey based tests of uncovered interest parity. In R. MacDonald & M.P. Taylor (eds.) *Exchange rate and open macroeconomics*. Cambridge: Mass. Basil Blackwell.
- [40] Mankiw, N. Gregory. 1986. The allocation of credit and financial collapse. *Quarterly Journal of Economics* 101 (3): 455—70.

-
- [41] McCallum, Bennett T. 1994. A reconsideration of the uncovered interest parity relationship. *Journal of Monetary Economics* 33: 105—32.
- [42] Meredith, Guy. 2007. Debt dynamics and global imbalances: some conventional views reconsidered. IMF Working Paper WP/07/4. International Monetary Fund, Washington, D.C., January 2007.
- [43] Obstfeld, Maurice & Kenneth Rogoff. 1998. Risk and exchange rates. NBER Working Papers 6694. National Bureau of Economic Research.
- [44] Rich, Robert & Joseph Tracy. 2004. Uncertainty and labour contract durations. *The Review of Economics and Statistics* 86 (1): 270—87.
- [45] Sa, Filipa & Francesca Viani. 2013. Shifts in portfolio preferences of international investors: an application to sovereign wealth funds. *Review of International Economics* 21 (5): 868—85.
- [46] Sanchez, Marcelo. 2008. The link between interest rates and exchange rates: do contractionary depreciations make a difference?. *International Economic Journal* 22 (1): 43—61.
- [47] Schmitt-Grohe, Stephanie & Martin Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61 (1): 163—85.
- [48] Sharpe, Steven A. 1997. The effect of consumer switching costs on prices: a theory and its application to the bank deposit market. *Review of Industrial Organization* 12: 79—94.
- [49] Taylor, Mark P. 1989. Expectations, risk and uncertainty in the foreign exchange market, some results based on survey data. *Manchester School of Economic and Social Studies* 2: 142—53.
- [50] Townsend, Robert M.. 1979. Optimal contracts and competitive markets with costly state verification. *Journal of Economic Theory* 21 (2): 265—93.
- [51] Ueda, Kozo. 2012. Banking globalization and international business cycles: cross-border chained credit contracts and financial accelerators. *Journal of International Economics* 86 (1): 1—16.
- [52] Uhlig, Harald. 1998. A toolkit for analyzing nonlinear dynamic stochastic models easily. *Quantitative Macroeconomics & Real Business Cycles* 123.

Appendix

1 The log-linearised model

The model consists of the equations (1)-(3), (5)-(7), and (12)-(31). For the alternative scenario of foreign bank debt, we replace (1) and (3) with (8) and (9). These equations determine the equilibrium dynamics of the variables

$$\left\{ \begin{array}{l} E_t, R_{Et}, R_t, \bar{\omega}_t, F_t, \phi_t, N_{Bt}, N_{Et}, Y_t, K_t, Q_t, I_t, L_t, l_t, \\ w_t, w_t^E, w_t^B, P_t, C_t, C_{Ht}, C_{Ft}, C_{Ht}^*, C_{Et}, C_{Bt}, A_t, \zeta_t \end{array} \right\}_{t=0}^{\infty}$$

given exogenous innovations to A_t, R_{Et}^* , and the shock to bank net worth ζ_t . This model is solved using standard linear perturbation techniques. This involves linearising the model. In this Appendix we list the log-linearised equations in order.

$$\widehat{\bar{\omega}_t \bar{\omega}} \frac{\bar{\Psi}_\omega}{\bar{\Psi}} + \widehat{R_{BANKt}} = \hat{R}_t + \frac{\bar{F}}{\bar{F} - \bar{N}_B} (\hat{F}_{t-1} - \widehat{N_{Bt-1}}) \quad (35)$$

$$\hat{R}_{t+1} = \mathcal{E}_t (\widehat{R_{t+1}^*} + \hat{E}_{t+1} - \hat{E}_t) \quad (36)$$

$$\mathcal{E}_t (\widehat{R_{BANKt+1}} - \hat{R}_{t+1}) = \mathcal{E}_t (\widehat{\bar{\omega}_{t+1}}) \left(\bar{\omega} \frac{\bar{\lambda} \omega}{\bar{\lambda}} - \bar{\omega} \frac{-\bar{\Gamma}_\omega + \bar{\lambda}_\omega \bar{\Psi} + \bar{\Psi}_\omega \bar{\lambda}}{1 - \bar{\Gamma} + \bar{\Psi} \bar{\lambda}} \right) \quad (37)$$

$$\begin{aligned} \widehat{N_{Bt}} \bar{N}_B &= \bar{N}_B \hat{\zeta}_t + \bar{w}^B \widehat{w_t^B} - \gamma^B \bar{F} \bar{R}_E \bar{\Gamma}_\omega \bar{\omega} \widehat{\bar{\omega}_t} \\ &\quad + \gamma^B \bar{F} \bar{R}_E (1 - \bar{\Gamma}) (\hat{F}_{t-1} + \widehat{R_{BANKt}}) \end{aligned} \quad (38)$$

$$\hat{\zeta}_t = \rho^\zeta \hat{\zeta}_{t-1} + \epsilon_t^\zeta \quad (39)$$

$$\widehat{C_{Bt}} = \hat{F}_{t-1} + \widehat{R_{BANKt}} - \frac{\bar{\Gamma}_\omega \bar{\omega}}{1 - \bar{\Gamma}} \widehat{\bar{\omega}_t} \quad (40)$$

$$\hat{L}_t = \nu \hat{l}_t + (1 - \nu) \hat{l}_{t-1} \quad (41)$$

$$0 = \mathcal{E}_t (\widehat{C_t} + \hat{R}_{t+1} - \widehat{C_{t+1}}) \quad (42)$$

$$\begin{aligned}
0 &= \hat{l}_{t-1}\nu(1-\nu)\left(-\chi(1+\psi)\bar{l}^\psi + \frac{\bar{w}}{\overline{PC}}\right) + \frac{w}{\overline{PC}}\nu(\hat{w}_t - \hat{P}_t - \hat{C}_t) \quad (43) \\
&+ \hat{l}_t\left(\bar{l}^\psi\chi\left(-\nu(\nu(2+\psi)-1) - \beta(1-\nu)^2\psi\right) + \frac{\bar{w}}{\overline{PC}}\nu(2\nu-1)\right) \\
&+ \mathcal{E}_t\left(\hat{w}_{t+1} - \hat{P}_{t+1} - \hat{C}_{t+1}\right)\beta(1-\nu)\bar{l}\frac{w}{\overline{PC}} \\
&+ \beta(1-\nu)\left(-\chi\nu(1+\psi)\bar{l}^\psi + \frac{\bar{w}}{\overline{PC}}(1+\nu)\right)\mathcal{E}_t\left(\hat{l}_{t+1}\right)
\end{aligned}$$

$$\hat{P}_t = (1-\gamma)\hat{E}_t \quad (44)$$

$$\widehat{C_{Ht}} = \hat{C}_t + \eta\hat{P}_t \quad (45)$$

$$\widehat{C_{Ft}} = \hat{C}_t - \eta\hat{P}_t \quad (46)$$

$$\widehat{C_{Ht}^*} = \eta\hat{E}_t \quad (47)$$

$$\hat{Y}_t = \hat{A}_t + \alpha\widehat{K}_t + (1-\alpha)(1-\Omega_E - \Omega_B)\hat{L}_t \quad (48)$$

$$\hat{A}_t = \rho^A\hat{A}_{t-1} + \epsilon_t^A \quad (49)$$

$$\hat{w}_t = \hat{Y}_t - \hat{L}_t \quad (50)$$

$$\widehat{w_t^E} = \hat{Y}_t \quad (51)$$

$$\widehat{w_t^B} = \hat{Y}_t \quad (52)$$

$$\overline{R_E}\widehat{R_{Et}} = -\overline{R_E}\hat{Q}_{t-1} + (1-\delta)\hat{Q}_t + (\overline{R_E} - (1-\delta))(\hat{Y}_t - \widehat{K}_t) \quad (53)$$

$$\widehat{N_{Et}} = \frac{\overline{w^E}}{\overline{N_E}}\hat{Y}_t + \gamma^E\overline{R_E}(\widehat{R_{Et}} + \widehat{N_{Et-1}}) \quad (54)$$

$$\widehat{C_{Et}} = \widehat{R_{Et}} + \widehat{N_{Et-1}} \quad (55)$$

$$\widehat{K_{t+1}} = (1-\delta)\widehat{K}_t + \delta\hat{I}_t \quad (56)$$

$$\hat{Q}_t = \xi(\widehat{K_{t+1}} - \widehat{K}_t) \quad (57)$$

$$\hat{Y}_t\bar{Y} = \overline{C_H}\widehat{C_{Ht}} + \overline{C_H^*}\widehat{C_{Ht}^*} + \overline{C_E}\widehat{C_{Et}} + \overline{C_B}\widehat{C_{Bt}} + \bar{I}\hat{I}_t \quad (58)$$

$$+ \mu\overline{G_\omega F R_E \omega \hat{w}_t} + \mu\overline{G F R_E}(\widehat{F_{t-1}} + \widehat{R_{BANKt}}) \quad (59)$$

$$\overline{\phi F}(\widehat{F}_t + \widehat{\phi}_t) = (\widehat{Q}_t + \widehat{K_{t+1}})\bar{K} - \widehat{N_{Et}}\bar{N_E} \quad (60)$$

$$\widehat{\phi}_t = \kappa\mathcal{E}_t(\widehat{R_{Et+1}} - \widehat{R_{Et+1}^*} + \widehat{E_{t+1}} - \widehat{E}_t) \quad (61)$$

where $\widehat{R_{BANKt}} = \bar{\phi}\widehat{R_{Et}} + (1 - \bar{\phi})(\widehat{R_{Et}^*} + \widehat{E_t} - \widehat{E_{t-1}})$. For foreign debt replace (35) and (37) with

$$\begin{aligned}\widehat{\bar{\omega}_t\bar{\omega}}\frac{\bar{\Psi}_\omega}{\bar{\Psi}} + \widehat{R_{BANKt}} &= \widehat{R_{Et}^*} + \widehat{E_t} - \widehat{E_{t-1}} + \frac{\bar{F}}{\bar{F} - \bar{N}_B}(\widehat{F_{t-1}} - \widehat{N_{Bt-1}}) \\ \mathcal{E}_t(\widehat{R_{BANKt+1}} - \widehat{R_{t+1}^*} - \widehat{E_{t+1}} + \widehat{E_t}) &= \mathcal{E}_t(\widehat{\bar{\omega}_{t+1}})\left(\bar{\omega}\frac{\bar{\lambda}\omega}{\bar{\lambda}} - \bar{\omega}\frac{-\bar{\Gamma}_\omega + \bar{\lambda}_\omega\bar{\Psi} + \bar{\Psi}_\omega\bar{\lambda}}{1 - \bar{\Gamma} + \bar{\Psi}\bar{\lambda}}\right)\end{aligned}$$

2 The optimal steady state bank portfolio

Recall from equation (31) that the bank portfolio allocation (i) was specified in an *ad hoc* manner and (ii) implied imperfect asset substitutability between home and foreign risky assets. In this Appendix, we use the method of Devereux and Sutherland (2011) in order to solve for the optimal portfolio of the bank and hence give a microfounded justification for this treatment of asset demand. This broadly follows the analysis conducted in Section 2 of Chapter 2. We also aim to show that this model predicts that banks optimally minimise mismatches on their balance sheets by holding similar proportions of foreign assets and liabilities.

2.1 Preliminaries

First, we must extend the model to allow the banks at home to obtain funding from home and abroad. The allocation of bank assets is now an endogenous decision (rather than governed by the *ad hoc* function ϕ). We suppose that banks hold F_H in the home asset and F_F in the foreign asset. Following Ueda (2012), the bank splits its net worth by the proportions $\{\theta, 1 - \theta\}$, with the former part signing a loan contract with home depositors and the latter signing a loan contract with foreign depositors. To illustrate,

the first contract specifies a threshold $\bar{\omega}$ and a quantity of leverage to be raised, which is some multiple of the part of bank net worth attributable to that contract θN_B . Hence there are now two contracts and two thresholds $\bar{\omega}$ and $\bar{\omega}^*$. There are two depositor participation constraints

$$\begin{aligned}\mathcal{E}_t \left[\theta \Psi_{t+1} \left(F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t} \right) \right] &= R_{t+1} \theta (F_{Ht} + F_{Ft} - N_{Bt}) \\ \mathcal{E}_t \left[(1 - \theta) \Psi_{t+1}^* \left(F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t} \right) \frac{E_t}{E_{t+1}} \right] &= R_{t+1}^* (1 - \theta) (F_{Ht} + F_{Ft} - N_{Bt})\end{aligned}$$

Furthermore, there are now two bank first-order conditions

$$\mathcal{E}_t \left(\frac{R_{Et+1} \Omega_{t+1}}{F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t}} \right) = \mathcal{E}_t \left(\frac{\theta \frac{\Gamma_{\omega t+1}}{\Psi_{\omega t+1}} R_{t+1} + (1 - \theta) \frac{\Gamma_{\omega^* t+1}^*}{\Psi_{\omega^* t+1}^*} R_{t+1}^* \frac{E_{t+1}}{E_t}}{F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t}} \right) \quad (62)$$

$$\mathcal{E}_t \left(\frac{R_{Et+1}^* \frac{E_{t+1}}{E_t} \Omega_{t+1}}{F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t}} \right) = \mathcal{E}_t \left(\frac{\theta \frac{\Gamma_{\omega t+1}}{\Psi_{\omega t+1}} R_{t+1} + (1 - \theta) \frac{\Gamma_{\omega^* t+1}^*}{\Psi_{\omega^* t+1}^*} R_{t+1}^* \frac{E_{t+1}}{E_t}}{F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t}} \right) \quad (63)$$

where $\Omega_{t+1} = \theta \left(1 - \Gamma_{t+1} + \Psi_{t+1} \frac{\Gamma_{\omega t+1}}{\Psi_{\omega t+1}} \right) + (1 - \theta) \left(1 - \Gamma_{t+1}^* + \Psi_{t+1}^* \frac{\Gamma_{\omega^* t+1}^*}{\Psi_{\omega^* t+1}^*} \right)$. The law of motion for bank net worth and bank consumption of goods become

$$\begin{aligned}N_{Bt} &= \left(\gamma^B \left(\frac{(F_{Ht-1} R_{Et} + F_{Ft-1} R_{Et}^* \frac{E_t}{E_{t-1}}) \times}{(\theta (1 - \Gamma_t) + (1 - \theta) (1 - \Gamma_t^*))} \right) + w_t^B \right) \zeta_t \\ C_{Bt} &= (1 - \gamma^B) \left(F_{Ht-1} R_{Et} + F_{Ft-1} R_{Et}^* \frac{E_t}{E_{t-1}} \right) (\theta (1 - \Gamma_t) + (1 - \theta) (1 - \Gamma_t^*))\end{aligned}$$

This parameterisation of θ is not as strong an assumption as it seems. As Ueda notes: “although the allocation of net worth used for borrowing from home and foreign lenders is exogenous, the allocation of borrowings between the two lenders is endogenously determined”. In other words, what is exogenously set is how the bank allocates its

net worth to home or foreign lenders. It remains the endogenous choice of banks to lever up on either part of their net worth as much or as little as they wish (in response to the differences in home and foreign riskless rates), with the aim that their total balance sheet is sufficiently large for them to make their desired asset purchases. We can motivate the choice of an exogenous θ by assuming adjustment costs in changing sources of deposit²⁷.

The non-financial sector is unchanged. As is typical in portfolio choice models, this non-linear model is rank deficient. This model is rank deficient. There are two more endogenous variables than there are model equations. In order to proceed, we take the approach of Devereux and Sutherland (2011), which involves two preliminary steps. First, we define the total assets held by the bank as some multiple of bank net worth $F_H + F_F \equiv N_B [\theta \chi(\bar{\omega}) + (1 - \theta) \chi(\bar{\omega}^*)]$. $\chi(\bar{\omega})$ and $\chi(\bar{\omega}^*)$ represent, respectively, the leverage obtained from the home and foreign depositor, respectively, as a multiple of bank net worth. It can be shown (see section 2.3) that $\chi(\bar{\omega}) = 1 + \frac{\Psi\lambda}{1-\Gamma}$, where $\lambda = \frac{\Gamma_{\omega}}{\Psi_{\omega}}$. This is an increasing function of $\bar{\omega}$. This definition allows us to eliminate F_F , bank holdings of foreign assets, from the non-linear model.

Second, we log-linearise the model. This is useful because F_H only appears in the non-linear model when multiplied by the excess return on home assets $(R_{Et+1} - R_{Et+1}^* \frac{E_{t+1}}{E_t})$ and so when we log-linearise, the first-order term $\widehat{F_H}$ disappears because it is multiplied by $\overline{R_E} - \overline{R_E} \frac{\overline{E}}{\overline{E}} = 0$. This solves the problem of rank deficiency.

²⁷Craig and Dinger (2013) find that volumes of deposits are rigid due to adjustment costs (e.g. Sharpe, 1997). For any change in the assets of a bank, deposits typically adjust by only $\sim 7\%$ of the asset change. Similarly Craig and Dinger (2010) and Dinger (2011) find that, the larger the geographic scope of a bank, the slower its retail interest rates adjust in response to money market rates, an indication that sources of funding are rigid.

2.2 The optimal steady state bank portfolio

Our aim now is to find $\frac{\overline{F_H}}{N_{B\chi}(\overline{\omega})}$, the steady state proportion of bank portfolio allocated to the home country. We use the two-step approach of Devereux and Sutherland. First, we need to find an arbitrage condition between home and foreign assets. Recall the bank's two first-order conditions (62) and (63). Combining these two equations, we get

$$\mathcal{E}_t \left(\frac{R_{Et+1} - R_{Et+1}^* \frac{E_{t+1}}{E_t}}{F_{Ht} R_{Et+1} + F_{Ft} R_{Et+1}^* \frac{E_{t+1}}{E_t}} \Omega_{t+1} \right) = 0 \quad (64)$$

Taking a second-order approximation of (64), we arrive at

$$\mathcal{E}_t \left[\widehat{R}_{Et+1}^X \left(1 + \left(\theta \widehat{\omega}_{t+1} + (1 - \theta) \widehat{\omega}_{t+1}^* \right) \frac{\omega \Psi \frac{\Gamma_\omega}{\Psi_\omega}}{1 - \Gamma + \Psi \frac{\Gamma_\omega}{\Psi_\omega}} \right) \right] = 0 \quad (65)$$

where $\widehat{R}_{Et+1}^X \equiv \widehat{R}_{Et+1} - \widehat{R}_{Et+1}^* - \widehat{E}_{t+1} + \widehat{E}_t$ is the excess return on home assets.

Equation (65) tells us that

$$\mathcal{E}_t \left(\widehat{R}_{Et+1}^X \right) = -1 \times \text{Cov} \left(\underbrace{\widehat{R}_{Et+1}^X}_{\substack{\text{home asset} \\ \text{excess return}}}, \underbrace{\left(\theta \widehat{\omega}_{t+1} + (1 - \theta) \widehat{\omega}_{t+1}^* \right)}_{\text{cost of funds}} \right) \frac{\overline{\omega} \overline{\Psi} \frac{\overline{\Gamma_\omega}}{\overline{\Psi_\omega}}}{1 - \overline{\Gamma} + \overline{\Psi} \frac{\overline{\Gamma_\omega}}{\overline{\Psi_\omega}}} \quad (66)$$

This second-order condition pins down the bank's portfolio balance²⁸. This equation simply says that the bank will prefer assets that provide more insurance value against a rise in the cost of funds.

Suppose the covariance between home excess return and the cost of funds is negative.

²⁸A second-order approximation is necessary because with a first-order approximation we get certainty equivalence behaviour and because the expected returns on both home and foreign assets are the same, banks would treat home and foreign assets as perfect substitutes.

Then if the cost of funds unexpectedly rises, the return on home assets falls and so home assets provide less insurance against the risk of a rise in the bank's funding costs (compared with foreign assets). According to (66), this means that home assets must then earn a positive excess return above foreign assets if there is to be no arbitrage. In other words, banks demand a positive risk premium on the asset that offers less insurance against the risk of hikes in funding costs.

The second and final step is to solve for the state-space solution of the log-linearised model, temporarily treating $\frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} \widehat{R}_{E,t+1}^X = \widehat{\pi}_{t+1}$ as an iid shock. For convenience, we set all shock variances to zero, except the firm technology shock and the shock to the foreign rate of return. Reading off the appropriate rows in the state-space solution, we then find (see section 2.5 for details)

$$\begin{aligned} \widehat{R}_{E,t+1}^X &= \mathbf{R}_1 \widehat{\pi}_{t+1} + \mathbf{R}_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{E,t+1}^* \end{bmatrix} \\ (\theta \widehat{\omega}_{t+1} + (1 - \theta) \widehat{\omega}_{t+1}^*) &= \mathbf{D}_1 \widehat{\pi}_{t+1} + \mathbf{D}_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{E,t+1}^* \end{bmatrix} + \mathbf{D}_3 [\text{predetermined variables}] \end{aligned}$$

Rearranging and substituting these expressions back into (66) gives us this restriction on $\overline{F_H}$

$$\frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} = \begin{array}{c} \text{fraction of bank portfolio} \\ \text{in home assets} \end{array} = [\mathbf{R}_2 \Sigma \mathbf{D}_2' \mathbf{R}_1' - \mathbf{D}_1 \mathbf{R}_2 \Sigma \mathbf{R}_2']^{-1} \mathbf{R}_2 \Sigma \mathbf{D}_2'$$

$$\text{where } \Sigma = \begin{bmatrix} \sigma^2 & 0 \\ 0 & \sigma^{*2} \end{bmatrix}.$$

This gives an expression for the steady state proportion of portfolio held in home assets. Figure 18 plots this portfolio balance as a function of the variance of the home

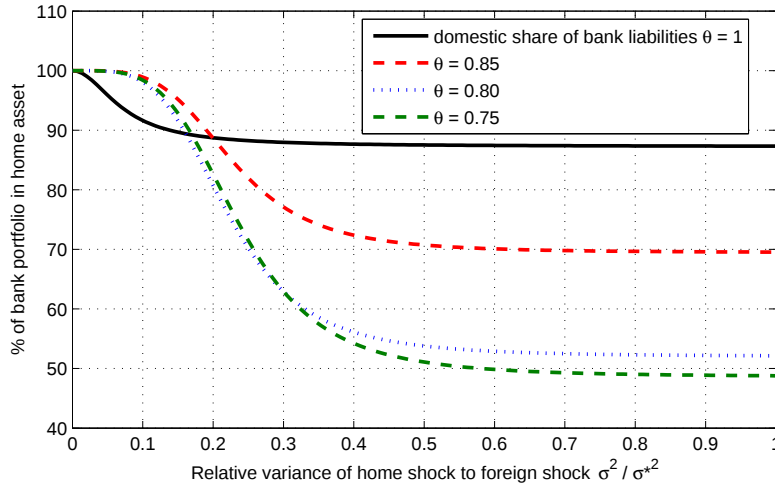
technology shock relative to the variance of the return on foreign assets $\frac{\sigma^2}{\sigma^{*2}}$. If there is no technology shock at home ($\frac{\sigma^2}{\sigma^{*2}} = 0$) the bank holds all of its portfolio in the home asset ($\frac{\overline{F_H}}{N_{BX}(\overline{\omega})} = 1$) because the home asset is now riskless. As the relative variance of home shock rises, the proportion of portfolio held at home decreases. This is a simple consequence of risk averse preferences of banks.

Furthermore, the proportion of the portfolio held at home decreases as the proportion of funding obtained from the home country (θ) decreases. This is a consequence of our arbitrage condition (66). As θ decreases, the bank obtains more of its funding from foreign depositors and so the cost of funds becomes more closely related to the foreign riskless rate and changes in the exchange rate. Home assets, being denominated in the home currency, now provide less of a hedge against rises in bank funding costs and so foreign assets are preferred more.

Essentially the bank balances its portfolio in a way to hedge against currency risks associated with obtaining funding from home and from abroad. So, in this section, we have found that banks do in fact hedge against foreign debt by holding roughly the same proportion of foreign assets. This replicates a key fact found by Bleakley and Cowan (2008). However, a small currency mismatch may still persist. Note that, in our calibration we chose $\frac{\overline{F_H}}{N_{BX}(\overline{\omega})} = 87.4\%$ to match Australian data. If we plug in the value of $\theta = 80\%$ into this extended model (also to match Australian data), then figure 18 implies that the ratio of standard deviations of home to foreign shocks is equal to around 0.15, which is within the 95% confidence interval estimated for this ratio using Australian data by Hodge, Robinson, and Stuart (2008)²⁹.

²⁹Estimates by Lees, Matheson and Smith (2007) and by Adolfson, Laseen, Linde and Villani (2005) imply that the mean estimate of this ratio of variances is 49% in New Zealand and 40% in Sweden, respectively.

Figure 18: Proportion of portfolio held in home assets



2.3 Details — Finding the functional forms of $\chi(\bar{\omega})$, $\chi(\bar{\omega}^*)$

In this subsection, we find the functional form for the leverage ratios $\chi(\bar{\omega})$ and $\chi(\bar{\omega}^*)$. Recall the representative bank's optimisation problem: it has split into two parts, proportion θ signing a debt contract with home depositors, and proportion $1 - \theta$ signing a debt contract with foreign depositors. We express next period bank return as

$$\underbrace{R_{bank}}_{\text{portfolio return}} \underbrace{N_B}_{\text{own net worth}} \left[\underbrace{\theta}_{\substack{\% \text{ of } N_B \\ \text{at home}}} \underbrace{\chi}_{\substack{\text{leverage} \\ \text{from home}}} \underbrace{(1 - \Gamma)}_{\substack{\text{bank's} \\ \text{share}}} + \underbrace{(1 - \theta)}_{\substack{\% \text{ of } N_B \\ \text{abroad}}} \underbrace{\chi^*}_{\substack{\text{leverage} \\ \text{from abroad}}} \underbrace{(1 - \Gamma^*)}_{\substack{\text{bank's} \\ \text{share}}} \right] \quad (67)$$

and the home depositor has participation constraint

$$\underbrace{\theta}_{\substack{\% \text{ of } N_B \\ \text{at home}}} \underbrace{N_B \chi}_{\substack{\text{total} \\ \text{portfolio}}} \underbrace{R_{bank}}_{\substack{\text{portfolio} \\ \text{return}}} \underbrace{\Psi}_{\substack{\text{depositor's} \\ \text{share}}} \geq \underbrace{\theta}_{\substack{\% \text{ of } N_B \\ \text{at home}}} \underbrace{N_B (\chi - 1)}_{\substack{\text{total bank} \\ \text{liabilities}}} \underbrace{R}_{\substack{\text{home} \\ \text{riskless rate}}} \quad (68)$$

and similarly the foreign depositor has participation constraint

$$(1 - \theta) N_B \chi^* R_{bank} \Psi^* \geq (1 - \theta) (N_B \chi^* - N_B) R^* \frac{E_{t+1}}{E_t} \quad (69)$$

The bank maximises the logarithm of (67) subject to constraints (68) and (69). This gives first order conditions

$$/\chi : 0 = \frac{\theta N_B R_{bank} (1 - \Gamma)}{\theta N_B R_{bank} \chi (1 - \Gamma) + (1 - \theta) N_B R_{bank} \chi^* (1 - \Gamma^*)} - \Lambda N_B (R\theta - \Psi R_{bank}) \quad (70)$$

$$/\bar{\omega} : 0 = \frac{\theta N_B R_{bank} \chi (-\Gamma_\omega)}{\theta N_B R_{bank} \chi (1 - \Gamma) + (1 - \theta) N_B R_{bank} \chi^* (1 - \Gamma^*)} + \Lambda N_B R_{bank} \theta \chi \Psi_\omega \quad (71)$$

$$/\chi^* : 0 = \frac{(1 - \theta) N_B R_{bank} (1 - \Gamma^*)}{\theta N_B R_{bank} \chi (1 - \Gamma) + (1 - \theta) N_B R_{bank} \chi^* (1 - \Gamma^*)} \quad (72)$$

$$\begin{aligned} & -\Lambda^* N_B \left(R^* \frac{E_{t+1}}{E_t} (1 - \theta) - \Psi^* R_{bank} \right) \\ /\bar{\omega}^* : 0 &= \frac{(1 - \theta) N_B R_{bank} \chi^* (-\Gamma_\omega^*)}{\theta N_B R_{bank} \chi (1 - \Gamma) + (1 - \theta) N_B R_{bank} \chi^* (1 - \Gamma^*)} + \Lambda^* N_B R_{bank} (1 - \theta) \chi^* \Psi_\omega^* \end{aligned} \quad (73)$$

where Λ and Λ^* are the Lagrange multipliers on (68) and (69) respectively. Combining (70) and (71) to eliminate Λ gives us

$$1 - \Gamma = \frac{\Gamma_\omega (R - \Psi R_{bank})}{R_{bank} \Psi_\omega} \quad (74)$$

Rearranging the constraints gives us

$$\text{constraint (68) : } \frac{R}{R_{bank}} = \frac{\theta \Psi N_B \chi}{\theta N_B (\chi - 1)} \quad (75)$$

$$\text{constraint (69) : } \frac{R^* \frac{E_{t+1}}{E_t}}{R_{bank}} = \frac{(1 - \theta) \Psi^* N_B \chi^*}{(1 - \theta) N_B (\chi^* - 1)} \quad (76)$$

We substitute (75) into (74) to get

$$\begin{aligned} 1 - \Gamma &= \frac{\Gamma_\omega}{\Psi_\omega} \left(\frac{\Psi\chi}{\chi - 1} - \Psi \right) \\ \chi &= 1 + \frac{\Psi \frac{\Gamma_\omega}{\Psi_\omega}}{1 - \Gamma} \end{aligned}$$

which is the expression we use in Appendix 2.1. Doing the same for (72), (73), and (76) gives $\chi^* = 1 + \frac{\Psi^* \frac{\Gamma_\omega^*}{\Psi_\omega^*}}{1 - \Gamma^*}$.

2.4 Details — Deriving the second order arbitrage equation

Combining (62) and (62) gives the equation

$$\begin{aligned} \mathcal{E}_t \left[\frac{R_{E,t+1} \left(\theta(1 - \Gamma_{t+1} + \Psi_{t+1}\lambda_{t+1}) + (1 - \theta)(1 - \Gamma_{t+1}^* + \Psi_{t+1}^*\lambda_{t+1}^*) \right)}{F_{H,t} R_{E,t+1} + F_{F,t} R_{E,t+1}^* \frac{E_{t+1}}{E_t}} \right] &= \\ \mathcal{E}_t \left[\frac{R_{E,t+1}^* \frac{E_{t+1}}{E_t} \left(\theta(1 - \Gamma_{t+1} + \Psi_{t+1}\lambda_{t+1}) + (1 - \theta)(1 - \Gamma_{t+1}^* + \Psi_{t+1}^*\lambda_{t+1}^*) \right)}{F_{H,t} R_{E,t+1} + F_{F,t} R_{E,t+1}^* \frac{E_{t+1}}{E_t}} \right] \end{aligned}$$

where $\lambda = \frac{\Gamma_\omega}{\Psi_\omega}$ and $\lambda^* = \frac{\Gamma_\omega^*}{\Psi_\omega^*}$. Essentially we have an expression of the form $\mathcal{E}_t \left(\frac{A_{t+1}B_{t+1}}{C_{t+1}} \right) = \mathcal{E}_t \left(\frac{D_{t+1}B_{t+1}}{C_{t+1}} \right)$. If we take a second-order approximation of this expression, we arrive at

$$\begin{aligned} \mathcal{E}_t \left(\begin{array}{c} \hat{A}_{t+1} + \hat{B}_{t+1} - \hat{C}_{t+1} + \hat{A}_{t+1} \hat{B}_{t+1} \\ - \hat{A}_{t+1} \hat{C}_{t+1} - \hat{B}_{t+1} \hat{C}_{t+1} + \hat{C}_{t+1}^2 \end{array} \right) &= \mathcal{E}_t \left(\begin{array}{c} \hat{D}_{t+1} + \hat{B}_{t+1} - \hat{C}_{t+1} + \hat{D}_{t+1} \hat{B}_{t+1} \\ - \hat{D}_{t+1} \hat{C}_{t+1} - \hat{B}_{t+1} \hat{C}_{t+1} + \hat{C}_{t+1}^2 \end{array} \right) \\ \mathcal{E}_t(\hat{A}_{t+1} + \hat{A}_{t+1} \hat{B}_{t+1} - \hat{A}_{t+1} \hat{C}_{t+1}) &= \mathcal{E}_t(\hat{D}_{t+1} + \hat{D}_{t+1} \hat{B}_{t+1} - \hat{D}_{t+1} \hat{C}_{t+1}) \\ \mathcal{E}_t[(\hat{A}_{t+1} - \hat{D}_{t+1})(1 + \hat{B}_{t+1} - \hat{C}_{t+1})] &= 0 \end{aligned}$$

We simplify by assuming that $\mathcal{E}_t[(\hat{A}_{t+1} - \hat{D}_{t+1})\hat{C}_{t+1}] = 0$ which in our context implies assuming that $\text{Cov}(\hat{R}_{bank}, \text{home asset return}) = \text{Cov}(\hat{R}_{bank}, \text{foreign asset return})$. This is a plausible simplification because the foreign return is an iid exogenous process and

so we can always scale the variance of the foreign shock so that this condition holds. This essentially means we can cross-multiply out the denominator in the expression above. So our arbitrage equation becomes

$$\mathcal{E}_t \left[R_{E,t+1} \begin{pmatrix} \theta(1-\Gamma_{t+1}+\Psi_{t+1}\lambda_{t+1})+ \\ (1-\theta)(1-\Gamma_{t+1}^*+\Psi_{t+1}^*\lambda_{t+1}^*) \end{pmatrix} \right] = \mathcal{E}_t \left[R_{E,t+1}^{\frac{E_{t+1}}{E_t}} \begin{pmatrix} \theta(1-\Gamma_{t+1}+\Psi_{t+1}\lambda_{t+1})+ \\ (1-\theta)(1-\Gamma_{t+1}^*+\Psi_{t+1}^*\lambda_{t+1}^*) \end{pmatrix} \right]$$

The second-order approximation of the left-hand side becomes

$$\widehat{R_E} + \frac{\overline{\omega}(-\overline{\Gamma_\omega} + \overline{\lambda_\omega \Psi} + \overline{\Psi_\omega \lambda})}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} + (1-\theta) \widehat{\omega}^*) + \frac{1}{2} \frac{1}{\overline{R_E}(1 - \overline{\Gamma} + \overline{\lambda \Psi})} \begin{bmatrix} \widehat{R_E \overline{R_E}} \\ \widehat{\omega \overline{\omega}} \\ \widehat{\omega^* \overline{\omega}} \end{bmatrix} \mathbf{M}$$

where $\mathbf{M} = \begin{bmatrix} 0 & \theta(-\overline{\Gamma_\omega} + \overline{\lambda_\omega \Psi} + \overline{\Psi_\omega \lambda}) & (1-\theta)(-\overline{\Gamma_\omega} + \overline{\lambda_\omega \Psi} + \overline{\Psi_\omega \lambda}) \\ \theta(-\overline{\Gamma_\omega} + \overline{\lambda_\omega \Psi} + \overline{\Psi_\omega \lambda}) & \overline{R_E} \theta(-\overline{\Gamma_{\omega\omega}} + \overline{\lambda_{\omega\omega} \Psi} + 2\overline{\Psi_\omega \lambda_\omega} + \overline{\Psi_{\omega\omega} \lambda}) & 0 \\ (1-\theta)(-\overline{\Gamma_\omega} + \overline{\lambda_\omega \Psi} + \overline{\Psi_\omega \lambda}) & 0 & \overline{R_E}(1-\theta)(-\overline{\Gamma_{\omega\omega}} + \overline{\lambda_{\omega\omega} \Psi} + 2\overline{\Psi_\omega \lambda_\omega} + \overline{\Psi_{\omega\omega} \lambda}) \end{bmatrix}.$

The left-hand side then simplifies to

$$\widehat{R_E} + \frac{\overline{\lambda_\omega \Psi \overline{\omega}}}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} + (1-\theta) \widehat{\omega}^*) + \frac{1}{2} \frac{(-\overline{\Gamma_{\omega\omega}} + \overline{\lambda_{\omega\omega} \Psi} + \overline{\Psi_{\omega\omega} \lambda} + 2\overline{\lambda_\omega \Psi_\omega}) \overline{\omega}^2}{(1 - \overline{\Gamma} + \overline{\lambda \Psi})} (\theta \widehat{\omega}^2 + (1-\theta) \widehat{\omega}^{*2}) \\ + \frac{\overline{\lambda_\omega \Psi \overline{\omega}}}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} \widehat{R_E} + (1-\theta) \widehat{\omega}^* \widehat{R_E})$$

By symmetry, the second-order approximation of the right-hand side is

$$\widehat{R_E^*} + \Delta \widehat{E} + \frac{\overline{\lambda_\omega \Psi \overline{\omega}}}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} + (1-\theta) \widehat{\omega}^*) + \frac{1}{2} \frac{(-\overline{\Gamma_{\omega\omega}} + \overline{\lambda_{\omega\omega} \Psi} + \overline{\Psi_{\omega\omega} \lambda} + 2\overline{\lambda_\omega \Psi_\omega}) \overline{\omega}^2}{(1 - \overline{\Gamma} + \overline{\lambda \Psi})} (\theta \widehat{\omega}^2 + (1-\theta) \widehat{\omega}^{*2}) \\ + \frac{\overline{\lambda_\omega \Psi \overline{\omega}}}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} (\widehat{R_E^*} + \Delta \widehat{E}) + (1-\theta) \widehat{\omega}^* (\widehat{R_E^*} + \Delta \widehat{E}))$$

Combining left-hand side and right-hand side gives the expression in (66)

$$\mathcal{E}_t \left[(\widehat{R_E} - \widehat{R_E^*} - \widehat{E}_{t+1} + \widehat{E}_t) \left(1 + \frac{\overline{\lambda_\omega \Psi \overline{\omega}}}{1 - \overline{\Gamma} + \overline{\lambda \Psi}} (\theta \widehat{\omega} + (1-\theta) \widehat{\omega}^*) \right) \right] = 0$$

2.5 Details — Deriving the expression for excess returns

The second step in the two-step approach is to solve for the state-space solution of the log-linearised model, treating $\frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} \widehat{R}_{Et+1}^X = \widehat{\pi}_{t+1}$ as an iid shock temporarily, and, for simplicity, eliminating all shocks except $\widehat{A}$ and $\widehat{R}_E^*$. The state space solution is found using the we do this numerically using the QZ method and specifically the algorithm in Uhlig (1998). Reading off the appropriate rows in the state-space solution, we can then find

$$\begin{aligned} \widehat{R}_{Et+1}^X &= \mathbf{R}_1 \widehat{\pi}_{t+1} + \mathbf{R}_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{Et+1}^* \end{bmatrix} \\ (\theta \widehat{\bar{\omega}}_{t+1} + (1 - \theta) \widehat{\bar{\omega}}_{t+1}^*) &= \mathbf{D}_1 \widehat{\pi}_{t+1} + \mathbf{D}_2 \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{Et+1}^* \end{bmatrix} + \mathbf{D}_3 [\text{predetermined variables}]' \end{aligned}$$

Recalling that $\frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} \widehat{R}_{Et+1}^X = \widehat{\pi}_{t+1}$, we can rearrange the above two expressions as

$$\begin{aligned} \widehat{R}_{Et+1}^X &= \frac{\mathbf{R}_2}{1 - \mathbf{R}_1 \frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}}} \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{Et+1}^* \end{bmatrix} \\ (\theta \widehat{\bar{\omega}}_{t+1} + (1 - \theta) \widehat{\bar{\omega}}_{t+1}^*) &= \left(\mathbf{D}_1 \frac{\mathbf{R}_2}{1 - \mathbf{R}_1 \frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}}} + \mathbf{D}_2 \right) \frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} \begin{bmatrix} \widehat{A}_{t+1} \\ \widehat{R}_{Et+1}^* \end{bmatrix} \end{aligned}$$

Rearranging and substituting back into (66) gives us the restriction on $\overline{F_H}$, namely

$$\frac{\overline{F_H}}{\overline{N_{B\chi}(\bar{\omega})}} = \text{fraction portfolio at home} = [\mathbf{R}_2 \Sigma \mathbf{D}_2' \mathbf{R}_1' - \mathbf{D}_1 \mathbf{R}_2 \Sigma \mathbf{R}_2']^{-1} \mathbf{R}_2 \Sigma \mathbf{D}_2'$$

where $\Sigma = \begin{bmatrix} \sigma^2 & 0 \\ 0 & \sigma^{*2} \end{bmatrix}$. Predetermined variables do not enter into the determination

of the steady state value of portfolio balance. Recall from section 1 that $\widehat{R}_{Et+1}^X =$

$\frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} - \widehat{Q}_t + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1})$ so the excess return is given by

$$\widehat{R_{E,t+1}^X} = \frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} - \widehat{Q}_t + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \widehat{R_{E,t+1}^*} - \Delta\widehat{E}_{t+1}$$

The excess return is zero in expectation (recall that the Devereux and Sutherland technique temporarily treats $\widehat{\phi}_{t+1}$ as an iid mean zero shock), so we arrive at

$$\begin{aligned} \mathcal{E}_t(\widehat{R_{E,t+1}^X}) &= \mathcal{E}_t\left(\frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} - \widehat{Q}_t + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \widehat{R_{E,t+1}^*} - \Delta\widehat{E}_{t+1}\right) \\ 0 &= \mathcal{E}_t\left(\frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \Delta\widehat{E}_{t+1}\right) - \widehat{Q}_t (\because \widehat{R_E^*} \text{ is mean-zero}) \\ \widehat{Q}_t &= \mathcal{E}_t\left(\frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \Delta\widehat{E}_{t+1}\right) \end{aligned}$$

so the excess return becomes

$$\begin{aligned} \widehat{R_{E,t+1}^X} &= \frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \Delta\widehat{E}_{t+1} - \widehat{R_{E,t+1}^*} \\ &\quad - \mathcal{E}_t\left(\frac{1-\delta}{\overline{R_E}}\widehat{Q}_{t+1} + \frac{\overline{R_E} - (1-\delta)}{\overline{R_E}} (\widehat{Y}_{t+1} - \widehat{K}_{t+1}) - \Delta\widehat{E}_{t+1}\right) \end{aligned}$$

which implies that predetermined variables do not enter into the expression for the excess return.

3 Two-period model using moral hazard friction

In this Appendix, we illustrate the main intuition of the Chapter using a simple stylised model. Because this model has minimal features, it allows us to demonstrate the basic premise in isolation. This Appendix also makes use of a different financial friction (moral hazard; e.g. Gertler & Karadi 2011) to that of the main model and demonstrates that

the same results go through.

3.1 Model

We broadly follow the specification of Cespedes, Chang and Velasco (2012). This is a model of a small open economy in two discrete time periods. In the first period ($t = 0$), domestic capital goods producers sell capital to firms that produce the final consumption good. In order to fund this purchase of capital goods, firms borrow from domestic banks, who in turn borrow from international capital markets. In the second period ($t = 1$), production and consumption occur.

Banks

Banks have an inherited net worth of N_B home goods and borrow D_0 foreign goods. In period $t = 0$, the bank can supply a total quantity of financial intermediation equal to

$$F_0 = N_B + D_0 E_0 \quad (77)$$

where E is the real exchange rate defined as the price of foreign goods relative to home goods (an increase in E indicates a real depreciation). In period $t = 1$, firms engage in production and repay the bank a return of R_1 per unit of intermediation. The bank then repays foreign creditors at the world interest rate R^* . The net profit of the bank in period 1 is thus $F_0 R_1 - D_0 E_1 R^*$. Note that the cost of servicing bank debt is augmented by the exchange rate next period because it is foreign-denominated.

Bank borrowing is subject to a collateral constraint

$$F_0 R_1 - D_0 E_1 R^* \geq \mu F_0 R_1 \quad (78)$$

where $\mu \in (0, 1)$. In other words, the net profit of the bank must be greater than some fraction of bank gross income. It is straightforward to motivate this constraint by positing, following Gertler and Kiyotaki (2010), that banks can default and abscond with proportion μ of its gross income. The constraint (78) ensures there is no default (in expectation).

If the constraint is non-binding, then using equations (77) and (78) we can show that the bank is willing to supply intermediation up to a multiple of its net worth $F_0 \leq \frac{N_B}{\mu}$. When the collateral constraint binds, the quantity of intermediation supplied is

$$F_0 = \frac{N_B}{1 - (1 - \mu) \frac{R_1}{R^* E_1 / E_0}} \quad (79)$$

The case where the constraint binds is of greater interest because it generates a positive finance premium $\frac{R_1}{R^* E_1 / E_0} > 1$. If the constraint does not bind and $F_0 = \frac{N_B}{\mu}$ (equivalently, if there is no constraint and $\mu = 0$), then the premium is zero and $R_1 = R^* \frac{E_1}{E_0}$. The existence of a wedge between the world interest rate and the bank's return can be interpreted as the premium that banks must earn in order to persuade foreign creditors to extend funds to them. Because the bank cannot perfectly commit to repaying its debts (i.e. $\mu > 0$), it must earn this premium in order to satisfy the collateral constraint.

Substituting (77) into (79) provides a relationship between the leverage of the bank and the spread of the bank's earnings over the repayment rate on foreign debt $\frac{R_1}{R^* E_1 / E_0}$

$$\text{debt-to-net worth ratio} = \frac{D_0 E_0}{N_B} = \frac{(1 - \mu) \frac{R_1}{R^* E_1 / E_0}}{1 - (1 - \mu) \frac{R_1}{R^* E_1 / E_0}} \quad (80)$$

So that when bank leverage increases, the external premium $\frac{R_1}{R^* E_1 / E_0}$ also increases. If R^* is taken as given and R_1 does not increase, then the burden of adjustment falls on the exchange rate, which must be *expected* to appreciate from period 0 to period 1 (i.e.

$E_1/E_0 < 1$). This appreciation represents the required decrease in the value of the foreign debt (equivalently, the increase in the value of bank earnings) from this period to the next in order to ensure that the collateral constraint remains satisfied. Furthermore, if, in addition, the required expected appreciation is greater than the long-run level of the exchange rate (i.e. $E_1/E_0 < E_1$) then it must be the case that the exchange rate must initially depreciate (i.e. $E_0 \uparrow$).

Capital goods producers

The behaviour of other agents is straightforward. There is assumed to be an endowment of investment goods N_C . Capital goods producers employ investment in period 0 I_0 is used to produce capital goods in period 1 K_1 using the technology $K_1 = \Omega I_0^\gamma$. The cost of investment goods is normalised to one and the price of capital Q_0 is taken as given. Capital goods producers solve

$$\max_{I_0} \{K_1 Q_0 - I_0\} \quad \text{subject to} \quad K_1 = \Omega I_0^\gamma$$

which yields the first order condition $I_0 = (\Omega \gamma Q_0)^{\frac{1}{1-\gamma}}$ and so the capital next period is given by $K_1 = \Omega (\Omega \gamma Q_0)^{\frac{\gamma}{1-\gamma}}$.

Firms

In period 0, firms choose the capital to maximise expected profit from production in period 1. Their production function is given by $Y_1 = AK_1^\alpha$. Firms solve

$$\max_{K_1} \{Y_1 - Q_0 K_1 R_1\} \quad \text{subject to} \quad Y_1 = AK_1^\alpha$$

which yields the first order condition that defines the return to bank intermediation

$$R_1 = \frac{\alpha A}{Q_0 K_1^{1-\alpha}} \quad (81)$$

Consumption

In period 1, final consumption takes place by firms, banks, and foreigners. Foreign demand is an increasing function of the exchange rate in period 1 E_1 : $\bar{C}^* = E_1^\eta$. Banks consume their entire net profit: $F_0 R_1 - D_0 E_1 R^*$. Firms consume the non-capital share of income: $(1 - \alpha)Y_1$.

3.2 Equilibrium in the two-period model

There are three markets to equilibrate. First, in the market for investment goods, equating demand with the endowment gives us

$$N_C = (\Omega \gamma Q_0)^{\frac{1}{1-\gamma}} \quad (82)$$

$$Q_0 = \frac{N_C^{1-\gamma}}{\Omega \gamma} \quad (83)$$

which implies that next period capital is given by

$$K_1 = \Omega N_C^\gamma \quad (84)$$

Second, in the market for financial intermediation, the supply of bank intermediation is given by equation (79). The demand for bank intermediation is given by the price of capital multiplied by the quantity of capital demanded by goods-producing firms:

Q_0K_1 . Using (83) and (84), this can be expressed as $\frac{N_C}{\gamma}$. So equilibrium in the financial market is given by

$$\underbrace{\frac{N_B}{1 - (1 - \mu)\frac{R_1}{R^*E_1/E_0}}}_{F_0} = \underbrace{\frac{N_C}{\gamma}}_{Q_0K_1}$$

Using the definition for R_1 in (81), we can simplify this condition to

$$\frac{E_1}{E_0} = \frac{(1 - \mu)\alpha A\gamma\Omega^\alpha}{R^*N_C^{1-\alpha\gamma}\left(1 - \gamma\frac{N_B}{N_C}\right)} \quad (85)$$

We call equation (85) the financial equilibrium condition and it defines, for a given endowment of bank net worth and investment goods, and for a given productivity of capital goods, the change in the exchange rate from period 0 to period 1 that is required to satisfy the collateral constraint. We suppose that in the original calibration, no exchange rate change is required $\frac{E_1}{E_0} = 1$. If the inherited net worth of banks (N_B) falls in period 0, then equation (85) indicates that the exchange rate must be expected to appreciate ($\frac{E_1}{E_0} < 1$). This is because the bank now needs more foreign credit than it did previously - its leverage rises, which (as equation (80) shows) means that foreign creditors demand a higher premium. And since the return on capital and the world interest rate are unchanged, the burden of adjustment falls on the exchange rate, which must be expected to appreciate. This appreciation from $t = 0$ to $t = 1$ raises the foreign-value of bank earnings (realised in period $t = 1$) relative to the foreign-value of bank liabilities (incurred at period $t = 0$). The equilibrium condition implied by equation (85) is represented by the straight red lines in figure 19. In the original steady state, the financial equilibrium condition is represented by the 45 degree line. No change in the exchange rate between $t = 0$ and $t = 1$ is required to satisfy the collateral constraint.

However, if N_B falls, the equilibrium schedule tilts down, to reflect the fact that an appreciation between the two periods is required.

Finally, we turn to final consumption of home goods. Equating supply Y_1 with the demand from banks, firms, and external consumers gives the condition

$$\bar{C}^* E_1^\eta = \alpha A K_1^\alpha - N_B R^* \frac{E_1}{E_0} - F_0 \left(R_1 - R^* \frac{E_1}{E_0} \right) \quad (86)$$

It is straightforward to show³⁰ that this is a positive relation between E_1 and $\frac{E_1}{E_0}$. This is intuitive: as the expected exchange rate appreciation decreases ($\frac{E_1}{E_0} \uparrow$), banks make a lower spread on their portfolio over the cost of servicing their debt, which lowers their net profits. Lower bank net profits lead to lower domestic demand, which requires a depreciated exchange rate ($E_1 \uparrow$) in order to equilibrate the goods market by raising external demand. Using equation (79) and rearranging, equation (86) becomes

$$E_0 = \frac{E_1 R^*}{(1 - \mu) R_1} - \frac{N_B R^*}{\bar{C}^* E_1^{\eta-1}} \quad (87)$$

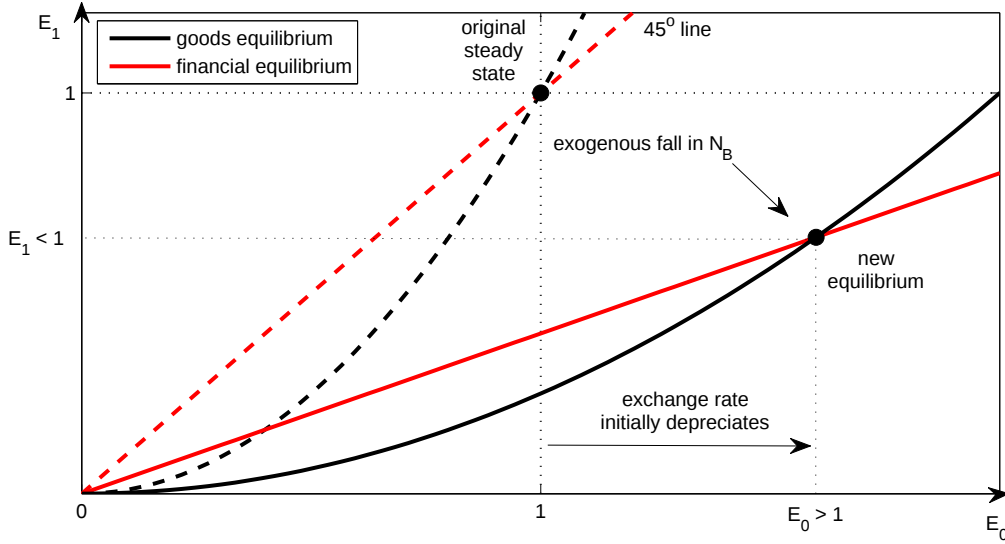
which is a positive relationship between E_0 and E_1 . We call equation (87) the goods market equilibrium condition. It is also straightforward to show that (87) is a convex relationship³¹. Equation (87) is represented by the convex curves in figure 19. The convexity arises from the fact that as E_1 increases, foreign demand for home goods rises, and so in order for the goods market to be in equilibrium, home demand for goods by banks must fall. This requires that, as E_1 increases, the rate of appreciation

³⁰ $\frac{d(\bar{C}^* E_1^\eta)}{d(E_1/E_0)} = (F_0 - N_B) R^* - \frac{dF}{d(E_1/E_0)} (R_1 - R^* E_1/E_0)$. Net bank borrowings are positive and the external finance premium is positive so $F_0 - N_B > 0$ and $R_1 - R^* E_1/E_0 > 0$. Furthermore, bank intermediation is decreasing in the expected exchange rate change $\frac{dF_0}{d(E_1/E_0)} < 0$. So it is clear that

$\frac{d(\bar{C}^* E_1^\eta)}{d(E_1/E_0)} > 0$.

³¹ $\frac{d^2 E_0}{dE_1^2} = -\eta(\eta - 1) \frac{N_B R^*}{\bar{C}^* E_1^{1+\eta}} < 0$ and so when we plot with E_1 on the vertical axis, this is a convex curve.

Figure 19: Response of the exchange rate to a fall in bank net worth



of the exchange rate declines ($\frac{E_1}{E_0} \uparrow$), which means that the gradient of the curve becomes steeper.

Equilibrium in the entire economy is then characterised by the two equations (85) and (87). These two equations pin down, as a function of the other model parameters, the required exchange rate change between periods 0 and 1, $\frac{E_1}{E_0}$, and the level of the exchange rate in period 1, E_1 , which together implicitly determine the exchange rate in period 0 E_0 .

3.3 Response to a financial crisis

We perform a simple experiment to illustrate the effects of a banking crisis. We consider an unanticipated fall in bank net worth N_B at the beginning of period 0. Consider the financial equilibrium condition. From inspection of equation (85), it is clear that a fall in bank net worth requires that the exchange rate appreciate from period 0 to 1 ($\frac{E_1}{E_0} < 1$). As discussed above, this is because, as bank leverage increases, the external finance

premium $R_1/(R^* E_1/E_0)$ must rise to compensate foreign creditors for extending credit to a more highly leveraged bank. And since R_1 and R^* do not move in the required directions, the exchange rate bears the burden of adjustment. We can also interpret the appreciation as the fall in the value of the foreign debt between this period and the next period (when repayment is due) that is required to keep the collateral constraint satisfied given that bank leverage has increased.

This means that in figure 19, the financial equilibrium schedule (originally at the 45 degree line, $\frac{E_1}{E_0} = 1$) tilts down to indicate that $\frac{E_1}{E_0} < 1$ in the new equilibrium.

Consider next the changes in the goods market equilibrium. It is clear from inspection of equation (87) that a decrease in N_B raises E_0 for any given E_1 . This means that in figure 19, the goods market equilibrium schedule shifts out. A fall in bank net worth lowers bank demand for consumption goods. In order to counter this effect and thus ensure equilibrium in the goods market, bank earnings must rise. This would imply that for any level of E_1 (that is, for any level of external demand), $\frac{E_1}{E_0}$ must fall and so the curve shifts out and to the right.

The new equilibrium is the intersection of the two new schedules in figure 19. The further that the goods market equilibrium schedule shifts out, the less-appreciated is the long-run level of the exchange rate. If the goods market equilibrium shifts out sufficiently far (which is the case shown in figure 19), the long-run change of the exchange rate (E_1) is smaller in magnitude than the change required by the financial equilibrium condition (i.e. $E_1/E_0 < E_1$) and so the exchange rate must initially depreciate at period zero ($E_0 \uparrow$). That is, the exchange rate jumps in period 0 so as to reflect its required change in future periods.

The initial depreciation, if there is one, represents the extent to which the home currency has been undervalued, relative to its long-run level, in order to entice foreign lenders to

extend credit to the domestic banking sector. It can be shown that as the financial friction becomes more severe (i.e. the collateral constraint binds more tightly $\mu \uparrow$), then for any given fall in bank net worth, the financial equilibrium schedule tilts down by more and the goods equilibrium schedule shifts out by more, resulting in a larger initial depreciation.

This is essentially the basic premise of this Chapter. An increase in bank leverage raises the external finance premium demanded of domestic banks. If the world interest rate does not fall and if the return on home investments does not rise, then it is the exchange rate that must adjust and by appreciating in future periods, so as to raise the spread on bank earnings above the cost of servicing debt. Equivalently, this expected future appreciation represents the decrease in the face value of foreign debt from the initial period to the next period (when repayment is due) that is required to satisfy the collateral constraint. If the long-run level of the exchange rate is not sufficiently appreciated to reflect the cumulative appreciation required by the financial equilibrium condition, then the exchange rate must depreciate in the initial period.

Note that the effect of a fall in home productivity of capital A has the same qualitative effects. The line representing financial equilibrium tilts down, and the curve representing goods equilibrium shifts out. And like in the case of a fall in bank net worth, the more the goods equilibrium curve shifts out, the smaller E_1/E_0 is relative to E_1 , which indicates a larger initial depreciation $E_0 \uparrow$.

Chapter 4: Credit policy, exchange rate volatility, and moral hazard

Simon Wan^{*†}

Abstract

In this Chapter, we extend the analysis of open economy financial frictions developed in the previous Chapter. Here, we perform a simple exercise in order to examine the effect of unconventional credit policy on a small open economy with financial frictions. We find that credit policy has positive effects on output and consumption by raising investment demand and by working against the effect of the financial friction. In terms of expanding output, it is more effective to extend government credit to banks than to the goods-producing sector because for each unit of government credit supplied to banks, banks - through leverage - can supply greater than one unit of financial intermediation to firms. However, lending to banks is a costly policy because it encourages greater risk-taking on the part of banks, leading to higher bank leverage. All else equal, this increases the volatility of the economy, raising the variances of consumption and of the exchange rate, which is welfare-deteriorating. We interpret this as indicative of the problem of moral hazard associated with a policy of providing support to failing banks.

JEL classification: F310, G010

Keywords: unconventional policy, credit policy, exchange rate volatility

^{*}Department of Economics, University of Oxford

[†]simon.wan@economics.ox.ac.uk

Contents

1	Introduction	267
2	Model	272
2.1	Banks	272
2.2	Capital goods producers	277
2.3	Firms	278
2.4	Households and General Equilibrium	279
2.5	Credit policy	280
3	Effects of Credit Policy	282
3.1	Parameterisation	283
3.2	Solution method and the risky steady state	284
3.3	Credit policy where $\theta = 0$	287
3.4	Credit policy where $\theta = 0.8$	291
3.5	Dynamic effects of credit policy	294
4	Concluding remarks	299
	Appendix	303
1	Finding the risky steady state	303
2	A note on the θ parameter	306

1 Introduction

This Chapter builds on the analysis of open economy financial frictions developed in Chapter 3. The model in this Chapter is broadly similar to the model in Chapter 3. In this Chapter, we perform a simple exercise in order to examine the properties of unconventional policy. Specifically, we examine credit policy, whereby the government can extend loans to the banking sector or to the goods-producing sector. We consider the effects of this class of policies on household welfare, national output, and exchange rate volatility. We analyse unconventional policy in the context of a model with financial frictions because unconventional credit policy is typically only effective where financial frictions are binding (Céspedes, Chang and Velasco, 2012; Céspedes, Chang and García-Cicco, 2011).

The 2008 financial crisis and the subsequent deployment of unconventional measures in response to this crisis have led to a surge in interest in unconventional policy (Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010; Gertler, Kiyotaki and Queralto, 2012). Notable examples in developed markets include the 2008 Troubled Asset Relief Program in the United States and the two bank bailout packages enacted in the United Kingdom. In developing markets, Céspedes, Chang and Velasco (2013) provide a survey of the recent Latin American experience that reveals the regular use of unconventional measures such as exchange rate intervention.

Recent analyses of unconventional policy (such as those listed above) have tended to focus on cases of closed economies. Following the common theme of this thesis, this Chapter extends the recent analysis to consider open economies and provides an explicit treatment of the effects of policy on exchange rates. The analysis in this Chapter is conducted by comparing the risky steady states (i.e. taking into account second-order moments) of economies with and without unconventional credit policies. We

also consider the dynamic response of the economy to shocks in the presence of these different policies.

The main finding of this Chapter is that credit policy - that is, government extending loans to the private sector in response to negative shocks - can have positive effects on the level of household consumption and national output. However, the overall effect on welfare may be ambiguous under the policy of lending support to failing banks. This is because this policy encourages the financial sector to become more highly-leveraged, which is welfare-deteriorating because it causes the variances of consumption and the exchange rate to increase *ceteris paribus*. In other words, unconventional credit policy may invite the problem of moral hazard.

We elaborate on this result. As is well understood from the previous Chapter and the financial frictions literature (Kiyotaki and Moore 1997; Bernanke, Gertler and Gilchrist 1999; Gertler, Gilchrist and Natalucci 2007; Gertler and Kiyotaki 2010), in the presence of financial frictions, there exist countercyclical risk premia that widen further after negative shocks to the economy. This causes the demand for investment and capital goods to fall further than in a world without financial frictions. Credit policy, by countering the rise of this risk premium after a negative shock, dampens the fall in investment. The capital stock, output, and thus consumption are all higher in the presence of unconventional credit policy.

However, the cost of such a policy is not negligible in the case where the government lends to the banking sector (as opposed to lending to goods-producing firms). Bank net worth is lower in the presence of an activist credit policy, reflecting the fact that banks anticipate government assistance following negative shocks and hence become more highly-leveraged. This has important effects on the first- and second-order properties of the model. Recall from the previous Chapter (and also the financial frictions literature

cited above) that the risk premium is a positive function of the bank's leverage ratio. The more highly-leveraged the bank becomes, the higher the risk premium rises in the event of a negative shock and so the greater the change in the other variables that have to bear the burden of adjustment after the shock, including (recall last Chapter's main result) the exchange rate. In turn, a higher variance of the exchange rate then implies (because it is the price of imports) a higher variance of household consumption, which is welfare-deteriorating.

A disclaimer: arguably the most prominent unconventional policy practised in recent times has been unconventional monetary policy in the form of quantitative easing (QE). Despite its prominence, we do not discuss QE. While QE and credit policy have some similarities (both aim to stimulate financial intermediation), the main transmission channels appear to be different. It has been argued (Joyce, Tong and Woods, 2011; Benford, Berry, Nikolov and Young, 2009) that QE operates through two channels: first, lowering the long end of the yield curve by encouraging the private sector to rebalance portfolios; second, raising inflation expectations by signalling a future loose monetary stance (both channels lower long-term borrowing costs). Furthermore, QE has been a response to a zero-interest-rate environment where conventional interest rate setting is not feasible. A model that captures the effect of QE would thus typically contain a term structure (e.g. Christensen and Rudebusch 2012; Jarrow and Li 2012), inflation expectations (e.g. Chen, Curdia and Ferrero 2012), or the zero lower bound (e.g. Curdia and Woodford 2010). These are features that we do not consider.

Related literature

There is an extensive body of literature on unconventional policy in the context of financial frictions. Christiano and Ikeda (2012) summarise the effects of different government

policies on models containing different financial frictions. The authors' main finding here is that, where frictions are binding, policy can typically achieve the first-best outcome (i.e. the outcome that would have obtained in the frictionless world). Gertler and Karadi (2011) focus on unconventional monetary policy (QE) and find that it can have substantial benefits in raising output and consumption. Likewise Gertler, Kiyotaki and Queralto (2012) find that macro-prudential and government credit policy can both have stabilising effects on financial markets. However, like in this Chapter, these authors find that the benefit of credit policy may be constrained by the increase in risk-taking (on the part of banks) that is encouraged by this policy. The problem of moral hazard was also introduced in Gertler and Kiyotaki (2010) and has been addressed in different settings by Chari and Kehoe (2013) and Farhi and Tirole (2012).

In terms of the model structure itself, this Chapter is broadly similar to Gertler and Karadi (2011) but extended to the open economy. The most important common features are (i) the formulation of the friction between financial intermediaries and depositors (a moral hazard friction) and (ii) the formulation of the way government conducts credit policy. There are some minor differences between our models. Consistent with the rest of this thesis, we consider a flexible price economy and hence the retail sector becomes redundant. We consider a fixed supply of labour in order to simplify the analysis. We also model the structure of the banking sector following Luk and Vines (2011).

In terms of the key question and objective addressed, this Chapter is broadly similar to Cespedes, Chang and Velasco (2012), who extend the findings of the closed economy literature above to an open economy setting. These authors find that, in an open economy, policy has positive effects on the exchange rate, as well as on investment, output, and consumption. This is significant because supporting the exchange rate (i) supports bank net worth (against negative “balance sheet effects”) and (ii) lowers

the spread and hence the leverage of banks. Supporting the exchange rate therefore has further positive effects on the economy. Their model, however, is of a simplified endowment economy in two time periods only. We aim to extend this model to a multi-period general equilibrium one.

Our contribution to the literature is twofold. First, this Chapter builds a bridge between (i) the microfounded DSGE approach used to analyse credit policy in closed economies (Gertler, Kiyotaki and Queralto, 2012; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010) and (ii) the open economy scope and objectives of Cespedes, Chang and Velasco (2012). That is, we share similar questions of interest with Cespedes *et al.* but we develop their model from a two-period endowment economy with non-optimising consumers into a fully developed one with an infinite time horizon, goods production, and microfounded consumption behaviour. This also means that we introduce important open economy features into the literature exemplified by Gertler and Karadi (2011). Most importantly, financial intermediaries in our model now face a portfolio problem in allocating assets between home and abroad and also obtain funding internationally.

Second, this Chapter considers the effect of policy on second-order moments. This is achieved by implementing the method of Coeurdacier, Rey and Winant (2011) to find the risk-adjusted stochastic steady state that pins down the variances and covariances of expectational variables in the model. This is how we examine the variances of exchange rates and consumption under different forms of credit policy, an issue that is not directly addressed by either Cespedes *et al.* or Gertler and Karadi (2011).

The remainder of this Chapter is organised as follows. Section 2 develops the model. Section 3 presents and discusses the results regarding credit policy. Section 4 concludes.

2 Model

The model in this Chapter is broadly similar to that in Chapter 3. The non-financial sectors in both Chapters are virtually identical. The main differences are: (i) we add unconventional credit policy; (ii) the financial friction here is the simpler moral hazard model. In this Chapter, we use the moral hazard friction because it is simpler and also because it allows us to illustrate fully the argument made in section 5.2 of Chapter 3 that this specification is qualitatively identical to the more complex BGG friction.

This is a small open-economy with a banking sector. In the non-financial side of the economy, a standard goods-producing firm issues assets to banks in order to fund capital goods purchases. Banks funds these asset purchases by borrowing from depositors. The financial friction, which resides in the loans between banks and depositors, is a standard moral hazard friction (e.g. Gertler and Kiyotaki, 2010). Because many of the features are similar to those in Chapter 3, we limit our discussion to a minimum.

2.1 Banks

The banking sector holds proportion α_t of its portfolio in assets issued by home firms that yield a gross return of R_E . It holds proportion $(1 - \alpha_t)$ of its portfolio in foreign assets that yield a gross return $\overline{R_E} \frac{E_{t+1}}{E_t}$. E is the real exchange rate defined as the price of foreign goods relative to home goods - a rise in E is a depreciation for home.

The bank borrows quantity D of home goods. The following assumption appears to be a departure from Chapter 3 but we will show below that it is not. Following Ueda (2012), we assume the bank splits its net worth into two subsidiaries by the proportions $\{\theta, 1 - \theta\}$, with one subsidiary borrowing from home depositors and the other borrowing

from foreign depositors¹. The home riskless rate is R . The foreign riskless rate is R^* but the cost (in terms of home goods) of borrowing from foreign depositors is augmented by the rate of exchange rate depreciation $R^* \frac{E_{t+1}}{E_t}$. In the absence of government policy, bank profit Π_{t+1} at the end of $t + 1$ is given by

$$\underbrace{(N_{Bt} + D_t)}_{\text{bank portfolio}} \underbrace{\left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t} \right)}_{\text{return on portfolio}} - \underbrace{D_t}_{\text{debt}} \underbrace{\left(\theta R_{t+1} + (1 - \theta) R_{t+1}^* \frac{E_{t+1}}{E_t} \right)}_{\text{return to depositors}} \quad (1)$$

(i) The moral hazard financial friction

Following Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), we assume that banks borrow from depositors subject to collateral constraints. Because we extend these models to an open economy, banks must satisfy two constraints rather than one (one for home and one for foreign depositors)

$$\underbrace{\theta (N_{Bt} + D_t) \mathcal{E}_t (R_{t+1}^{bank})}_{\text{bank income attributable to home depositors}} - \underbrace{\theta D_t R_{t+1}}_{\text{amount owed to home depositors}} \geq \underbrace{\mu}_{\text{\% bank can steal}} \underbrace{\theta (N_{Bt} + D_t) \mathcal{E}_t (R_{t+1}^{bank})}_{\text{bank income attributable to home depositors}} \quad (2)$$

$$(1 - \theta) (N_{Bt} + D_t) \mathcal{E}_t (R_{t+1}^{bank}) - (1 - \theta) D_t R_{t+1}^* \frac{E_{t+1}}{E_t} \geq \mu (1 - \theta) (N_{Bt} + D_t) \mathcal{E}_t (R_{t+1}^{bank}) \quad (3)$$

where $R_{t+1}^{bank} \equiv \alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t}$. These constraints are motivated by supposing that the bank can default and abscond with proportion μ of gross income. (2) and (3) ensure that absconding does not occur. (2) (or (3)) states that the bank net profit

¹As in Ueda, these fractions of home and foreign liabilities have to be parameterised because, in equilibrium, UIP holds and so in expectation the cost of borrowing from home and abroad are equal. Thus, up to a first-order approximation, these shares are indeterminate and hence have to be fixed as parameters. This, however, is not as strong an assumption as it appears - see Appendix 2.

attributable to the home (or foreign) depositor must be greater than or equal to the proportion of revenue attributable to the home (or foreign) depositor that the bank can abscond with.

Because unconventional policy is only relevant where financial frictions are binding (Céspedes, Chang and Velasco, 2012; Céspedes, Chang and Garcia-Cicco, 2011), we focus on the case where (2) and (3) bind. Rearranging (2) and (3) and imposing equality gives

$$\frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t} \right)}{R_{t+1}} = \frac{D_t}{(1 - \mu) (N_{Bt} + D_t)} \quad (4)$$

$$\frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t} \right)}{\mathcal{E}_t \left(R_{t+1}^* \frac{E_{t+1}}{E_t} \right)} = \frac{D_t}{(1 - \mu) (N_{Bt} + D_t)} \quad (5)$$

(4) and (5) define the spread on bank earnings above the riskless rates. We can interpret this spread as the premium that depositors demand to compensate for the possibility of absconding. The spread rises as the financial friction worsens (i.e. as the proportion of assets the bank can abscond with rises $\mu \uparrow$) and as the bank's leverage ratio increases ($\frac{D}{N_B} \uparrow$), as in Chapter 3².

By combining (4) and (5), we get the uncovered interest parity condition

$$\mathcal{E}_t(R_{t+1}) = \mathcal{E}_t \left(R_{t+1}^* \frac{E_{t+1}}{E_t} \right) \quad (6)$$

The reason why this condition holds is straightforward. The bank is conducting arbitrage between its two sources of funding. If the home riskless rate were lower than the foreign one, then the bank could lower its funding costs by obtaining more borrowing from home and less abroad. This would lower financial inflows, putting downward

²As leverage rises, the incentive to abscond increases and so depositors require a higher spread to compensate.

pressure on the exchange rate until it is so under-valued that its subsequent appreciation ($\frac{E_{t+1}}{E_t} \downarrow$) equalises home and foreign riskless rates in a common currency, making the bank indifferent between borrowing from home and abroad. We could replace (5) with the UIP condition (6). Hence this model is qualitatively similar to the model in Chapter 3 and the θ parameter disappears. The question then is: if UIP holds, why do we model both types of depositors? That is, why does the source of deposits matter? The reason is that, while UIP ensures that home and foreign riskless rates are equal (in a common currency) *in expectation*, in the period when a shock occurs, *unanticipated changes* in the exchange rate will cause *realised* home and foreign riskless rates to differ and so the denomination of debt will matter. (Recall Chapter 3 section 2.6.)

(ii) Bank portfolio allocation

Finally, we specify how the bank decides to split its portfolio between home and foreign assets. The bank can re-optimize each period and it exhibits mean-variance preferences such that it solves (where $\Pi_{t+1} \equiv$ profit as given in (1))

$$\max_{\alpha_t} \mathcal{E}_t(\Pi_{t+1}) - \frac{1}{2} \text{Var}(\Pi_{t+1})$$

This yields a first-order condition

$$\alpha_t = \frac{\mathcal{E}_t\left(R_{Et+1} - \overline{R_E} \frac{E_{t+1}}{E_t}\right) + \left(\text{Var}(E_{t+1}) \frac{\overline{R_E}}{E_t} - \text{Cov}(R_{Et+1}, E_{t+1})\right) \left(\frac{(N_{Bt} + D_t) \overline{R_E} - D_t(1-\theta)R_{t+1}^*}{E_t}\right)}{(N_{Bt} + D_t) \left[\text{Var}(R_{Et+1}) + \left(\frac{\overline{R_E}}{E_t}\right)^2 \text{Var}(E_{t+1}) - 2 \frac{\overline{R_E}}{E_t} \text{Cov}(R_{Et+1}, E_{t+1})\right]} \quad (7)$$

Equation (7) has a standard CAPM interpretation. Demand for the home asset rises as its expected excess return rises $\mathcal{E}_t\left(R_{Et+1} - \overline{R_E} \frac{E_{t+1}}{E_t}\right) \uparrow$; it falls as the return becomes

riskier ($\text{Var}(R_E) \uparrow$); it rises as the other (foreign) asset becomes riskier ($\text{Var}(E) \frac{\overline{R_E}}{E} \uparrow$ in the numerator). In the numerator of (7), the effect of the term $\text{Cov}(R_E, E)$ can be decomposed into two effects. (i) One effect is negative $-\text{Cov}\left(R_{Et+1}, E_{t+1} \frac{\overline{R_E}}{E_t}\right) (N_B + D)$: demand for the home asset falls if the asset offers less diversification against the other (foreign) asset³. (ii) The second effect is positive $+\text{Cov}\left(R_{Et+1}, E_{t+1} \frac{R^*}{E_t}\right) D(1 - \theta)$ because the more highly correlated are the home asset return and the exchange rate, the more the home asset hedges against rises in foreign borrowing costs. Notice that in the extreme case where $\theta = 1$ (i.e. the bank's debt is completely home-denominated), this second term disappears because the need to hedge against risks to borrowing costs is eliminated⁴.

(iii) Evolution of net worth

We round off our discussion of the banking sector with an equation describing the evolution of bank net worth. At the end of period t (when the bank decides on purchases of assets that pay returns in $t + 1$), bank net worth is given by

$$N_{Bt} = \nu_t \left\{ \gamma^B \left[\left(\alpha_{t-1} R_{Et} + (1 - \alpha_{t-1}) \overline{R_E} \frac{E_t}{E_{t-1}} \right) (N_{Bt-1} + D_{t-1}) - D_{t-1} \left(\theta R_t + (1 - \theta) R_t^* \frac{E_t}{E_{t-1}} \right) \right] + w_t^B \right\} \quad (8)$$

As in Chapter 3, $\gamma^B \in (0, 1)$ is a survival parameter ensuring that banks never outgrow the need to borrow from depositors. w^B is bank labour income (bank labour supply is fixed at one). ν is a unit-mean shock to bank net worth following the exogenous process

$$\log(\nu_t) = \rho^\nu \log(\nu_{t-1}) + \epsilon_t^\nu \text{ where } \epsilon_t^\nu \sim (0, \sigma_\nu^2) \quad (9)$$

³If the home asset's return becomes more highly correlated with the foreign asset's return, there is less reason to hold home assets over foreign assets.

⁴Recall that the only risky component of borrowing costs is the exchange rate, since R_{t+1} and R_{t+1}^* are known at time t .

To sum up the bank's decision-making process. At the end of t , given the macrovariables R_E, E, R, R^* and its inherited net worth N_B , the bank decides how to split its portfolio between home and foreign risky assets α_t . This determines the expected return on the bank's portfolio R^{bank} and hence the spread $\frac{R^{bank}}{R}$. This, in combination with the collateral constraint of the bank (2), determines how much the bank can borrow in total D and hence how large its total portfolio is. Risky assets pay returns in $t+1$, the bank repays depositors, and net profit determines new net worth at end of $t+1$.

2.2 Capital goods producers

The remainder of the model broadly follows Chapter 3 (which mainly follows Luk and Vines [2011]). Capital evolves according to (where ξ represents cost of adjustment)

$$K_{t+1} = (1 - \delta) K_t + I_t - \frac{\xi (K_{t+1} - K_t)^2}{2 K_t} \quad (10)$$

At the end of each period t , capital goods producers buy undepreciated capital from firms (at the prevailing price Q_t), combine these with investment goods (that cost P_H), and sell home firms a stock of K_{t+1} capital goods for goods production in $t+1$. This implies that capital goods producers solve

$$\max_{I_t} \{Q_t K_{t+1} - (1 - \delta) Q_t K_t - P_{Ht} I_t\} \text{ subject to (10)}$$

This yields the first-order condition

$$Q_t = P_{Ht} \left(1 - \xi + \xi \frac{K_{t+1}}{K_t} \right) \quad (11)$$

2.3 Firms

The home goods-producing firm employs a Cobb-Douglas technology (household, firm, and bank labour supply are fixed $L, L_E, L_B \equiv 1$) for $\phi \in (0, 1)$

$$Y_t = A_t K_t^\phi L_t^{(1-\Omega_E-\Omega_B)(1-\phi)} L_{Et}^{\Omega_E(1-\phi)} L_{Bt}^{\Omega_B(1-\phi)} \quad (12)$$

The exogenous level of productivity with mean $\bar{A}$ follows the process

$$\log(A_t/\bar{A}) = \rho^A \log(A_{t-1}/\bar{A}) + \epsilon_t^A \text{ where } \epsilon^A \sim (0, \sigma_A^2) \quad (13)$$

The firm must purchase capital one period in advance. At the same time, it sells any non-depreciated capital back to capital producers. The firm funds capital purchases by issuing assets to banks that pay R_E . The firm thus solves, subject to the production function (12) (where w, w^E, w^B are labour wages)

$$\max_{K, L, L_E, L_F} \left\{ \mathcal{E}_t \left[Y_{t+1} - w_{t+1} L_{t+1} - w_{t+1}^E L_{Et+1} - w_{t+1}^B L_{Bt+1} + (1 - \delta) Q_{t+1} K_{t+1} - R_{Et+1} Q_t K_{t+1} \right] \right\}$$

Wage equations for firms and for banks ($L_E = L_B = 1$) and the realised return on capital are given by (Ω_E, Ω_B are labour shares of the firm and bank)

$$w_t^E = (1 - \phi) \Omega_E Y_t \quad (14)$$

$$w_t^B = (1 - \phi) \Omega_B Y_t \quad (15)$$

$$R_{Et} = \frac{1}{Q_{t-1}} \left((1 - \delta) Q_t + \phi \frac{Y_t}{K_t} \right) \quad (16)$$

Firms have net worth N_{Et} that is subject to the survival parameter $\gamma^E \in (0, 1)$

$$N_{Et} = \gamma^E R_{Et} N_{Et-1} + w_t^E \quad (17)$$

2.4 Households and General Equilibrium

Equations describing the household are identical to in previous Chapters. Household optimisation (with log-utility) yields a familiar Euler equation (and the UIP condition (6))

$$\mathcal{E}_t \left(\frac{C_t R_{t+1}}{C_{t+1}} \right) \beta = 1 \quad (18)$$

where β is the discount factor⁵.

The price index and internal and external demand for home goods are given by (Gali and Monacelli, 2005; Gertler, Gilchrist and Natalucci, 2007)

$$P_t = \left[\gamma P_{Ht}^{1-\eta} + (1-\gamma) P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (19)$$

$$C_{Ht} = \gamma C_t \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} \quad (20)$$

$$C_{Ht}^* = \bar{C}^* \left(\frac{P_{Ht}}{E_t} \right)^{-\eta} \quad (21)$$

where γ represents home bias in goods consumption and η is the price elasticity of substitution between home and foreign goods. We take the home good as a numeraire $P_H = 1$ (Sa and Viani, 2013).

Goods market equilibrium is given by equating the supply of and demand for the home good (where the last two terms represent firm and bank consumption)

$$Y_t = C_{Ht} + C_{Ht}^* + I_t + (1 - \gamma^E) R_{Et} N_{Et-1} + (1 - \gamma^B) \frac{N_{Bt} - w_t^B}{\gamma^B} \quad (22)$$

⁵Following Gertler, Gilchrist and Natalucci (2007), we attach a small premium to the foreign riskless rate R^* which is an increasing function of total net household indebtedness. This ensures stationarity of this small open economy model (Schmitt-Grohe and Uribe, 2003). We set the elasticity of R^* with respect to net debt close enough to zero such that this does not affect the model dynamics but ensures that household debt (and hence consumption) revert to trend. R^* varies by a sufficiently small margin in our simulations that it can be thought of as constant.

Equilibrium in the market for home assets equates bank demand with firm supply (where D^* is foreign demand for home risky assets)

$$\alpha_t (N_{Bt} + D_t) + D_t^* = Q_t K_{t+1} - N_{Et} \quad (23)$$

2.5 Credit policy

We consider two types of credit policy. Following Cespedes *et al.*, we assume that the government can frictionlessly (i.e. not subject to a collateral constraint) borrow from world financial markets at the world riskless rate $R_{t+1}^* \frac{E_{t+1}}{E_t}$.

(i) Policy 1 — Government lends to Firms

Following Cespedes *et al.*, the first type of policy we consider is one where the government uses the funds obtained from international markets to purchase quantity X_t of the home firm's asset. In the next period, the government repays its creditors and any profit $X_t (R_{Et+1} - R_{t+1}^* \frac{E_{t+1}}{E_t})$ is transferred as a lump sum subsidy to households. Following Gertler and Karadi (2011) and Gertler, Kiyotaki and Queralto (2012), X is a fraction Ψ of outstanding assets, where Ψ is an increasing function of the risk premium at home. The government, in effect, targets the risk premium.

$$X_t = \Psi_t (Q_t K_{t+1} - N_{Et}) \quad (24)$$

$$\Psi_t = \Psi + \lambda \mathcal{E}_t \left(\log \left(\frac{R_{Et+1}}{R_{t+1}} \right) - \log \left(\frac{\overline{R_E}}{\overline{R}} \right) \right) \quad (25)$$

The asset market equilibrium condition (equation (23)) becomes

$$X_t + \alpha_t (N_{Bt} + D_t) + D_t^* = Q_t K_{t+1} - N_{Et} \quad (26)$$

(ii) Policy 2 — Government lends to Banks

Again following Cespedes *et al.*, the second policy we consider is one where the government obtains X_t from international markets to lend to the home bank at the foreign rate but not subject to a collateral constraint. We can interpret this as the central bank lending its foreign reserves to home banks at the discount window. In the next period, the government receives repayment and cancels its own debt in world markets. The government sets X_t in response to changes in bank net worth. In effect, the government is partially recapitalising banks whose net worth has fallen.

$$X_t = X + \Psi_t \left(\frac{\overline{N_B}}{N_{Bt}} \right) \quad (27)$$

$$\Psi_t = \Psi + \kappa \mathcal{E}_t \left(\log \left(\frac{R_{Et+1}}{R_{t+1}} \right) - \log \left(\frac{\overline{R_E}}{\overline{R}} \right) \right) \quad (28)$$

Equations (4), (5), (23), (7), and (8) become, respectively

$$\frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t} \right)}{R_{t+1}} = \frac{D_t}{(1 - \mu) (N_{Bt} + D_t + X_t)} \quad (29)$$

$$\frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R_E} \frac{E_{t+1}}{E_t} \right)}{\mathcal{E}_t \left(R_{t+1}^* \frac{E_{t+1}}{E_t} \right)} = \frac{D_t}{(1 - \mu) (N_{Bt} + D_t + X_t)} \quad (30)$$

$$\alpha_t (N_{Bt} + D_t + X_t) + D_t^* = Q_t K_{t+1} - N_{Et} \quad (31)$$

$$\alpha_t = \frac{\mathcal{E}_t \left(R_{Et+1} - \overline{R_E} \frac{E_{t+1}}{E_t} \right) + \left(\begin{array}{c} \text{Var} (E_{t+1}) \frac{\overline{R_E}}{E_t^2} - \\ \frac{1}{E_t} \text{Cov} (R_{Et+1}, E_{t+1}) \end{array} \right) \left(\begin{array}{c} (N_{Bt} + D_t + X_t) \overline{R_E} \\ - (D_t (1 - \theta) + X_t) R_{t+1}^* \end{array} \right)}{(N_{Bt} + D_t + X_t) \left[\text{Var} (R_{Et+1}) + \left(\frac{\overline{R_E}}{E_t} \right)^2 \text{Var} (E_{t+1}) - 2 \frac{\overline{R_E}}{E_t} \text{Cov} (R_{Et+1}, E_{t+1}) \right]} \quad (32)$$

$$N_{Bt} = \nu_t \left\{ \gamma^B \left[\begin{array}{c} \left(\alpha_{t-1} R_{Et} + (1 - \alpha_{t-1}) \overline{R_E} \frac{E_t}{E_{t-1}} \right) (N_{Bt-1} + D_{t-1} + X_{t-1}) \\ - D_{t-1} \left(\theta R_t + (1 - \theta) R_t^* \frac{E_t}{E_{t-1}} \right) - X_{t-1} R_t^* \frac{E_t}{E_{t-1}} \end{array} \right] + w_t^B \right\} \quad (33)$$

As we see from (29) and (30), this policy has the effect of raising the value of the bank's internal capital (i.e. its pledgeable collateral) by amount X_t ⁶.

We assumed that the government borrows from world capital markets to be consistent with Cespedes *et al.* (which would reflect a very small economy with insufficient savings at home). However, very little would change if we assumed that the government borrowed at the home deposit rate R instead (reflecting a larger and more advanced economy where the government can raise non-dollarised debt)⁷.

3 Effects of Credit Policy

The no-policy model consists of equations (4)-(5), (7)-(23). Under the credit policy where government lends to firms, we add (24)-(25) and replace (23) with (26). Under the credit policy where government lends to banks, we add (27)-(28) and replace (4)-(5), (7)-(8), and (23) with (29)-(33). These equations determine the equilibrium dynamics of the variables

$$\left\{ \alpha, D, Q, K, N_B, N_E, R_E, R, E, C, C_H, C_H^*, P, I, Y, w^B, w^E, A, \nu, X, \Psi \right\}_{t=0}^{\infty}$$

given the exogenous processes for ϵ^A, ϵ^ν . We now proceed to test this model.

⁶The collateral constraint for home depositors becomes $\theta R^{bank} (N_B + D + X) - \theta DR - XR^* \frac{E_{t+1}}{E_t} \geq \mu \theta R^{bank} (N_B + D + X) - XR^* \frac{E_{t+1}}{E_t}$. Notice that, even if the bank defaults on its loan with private depositors, it still repays the government. This arises from our assumption that the government can enforce loans contracts with banks so effectively that lending between governments and banks is not subject to a collateral constraint. Because banks cannot abscond with X , depositors treat X as part of the internal capital of the bank, together with N_B . Rearranging this new constraint gives us (29).

⁷The equations describing the policy [1] of lending to firms would not change at all. In the policy [2] of lending to banks, the only changes would occur in equation (32) and (33). The change in (32) does not matter because it is a forward-looking equation and UIP holds (i.e. home and foreign riskless rates are equal in expectation). (33) is backward-looking. However, the riskless rate appears in the term $X_{t-1} R_t^* \frac{E_t}{E_{t-1}}$. In the initial period of the shock $X_{t-1} \approx 0$ (X is less than 1% of N_B in steady state) and therefore the unanticipated change in exchange rate (in the initial period) would have little effect on (33).

3.1 Parameterisation

We set the parameters using the values in table 1. Since the values are in many cases identical to those in Chapter 3, we limit our discussion to a minimum.

- $\phi, \beta, \delta, \Omega_B, \Omega_E, \xi, \eta, \gamma$. These are within standard values used in the literature. See our discussion in Chapter 3.
- γ^E, γ^B . These are chosen to meet three steady state targets to match Australian data (to roughly match a small open economy, as in Chapter 3). These targets are (i) external finance premium $(\bar{R}_E - \bar{R}) = 0.005$ per quarter; (ii) firm leverage $\frac{\bar{K}}{\bar{N}_E} = 2.1$; (iii) capital-to-bank-net-worth ratio $\frac{\bar{K}}{\bar{N}_B} = 9.2$.
- μ . The fraction of capital that can be diverted by banks is set to 0.25. Typically this parameter is computed to meet the targets set above. However, in our model, where the bank can hold home and foreign assets (i.e. there is an additional parameter α), this is not feasible. The value we choose is in the range of values used in the literature (e.g. Gertler, Kiyotaki and Queralto [2012] use a value of 0.264). We perform some robustness checks on this choice of parameter value. We find that it affects the cardinal level of first-order moments in each risky steady state, but does not affect the ordinal comparison between steady states.
- $\sigma_\nu, \sigma_A, \rho^\nu, \rho^A$. Standard deviations of the exogenous shocks are set at 0.10. Autoregressive coefficients are set at 0.60. This implies that a standard deviation of output growth of around 1.5%, which lies within the range of growth standard deviation targeted by Gertler, Kiyotaki and Queralto (2012) (1.09% to 2.53%). These values pin down the second-order moments of the model. Changing them scales each value by similar proportions. We perform robustness checks and find

Table 1: Computed and calibrated parameters

Parameter/variable	Value
Capital share of income ϕ	0.35
Discount factor β	0.99
Depreciation rate δ	0.025
Firm and bank labour supply share Ω_B, Ω_E	0.01
Capital adjustment cost ξ	10
Price elasticity of substitution η	1.5
Home bias in consumption γ	0.85
Firm survival parameter γ^E	0.9837
Bank survival parameter γ^B	0.9669
Proportion of assets that bank can divert μ	0.25
Domestic share of bank liabilities θ	{0, 0.8}
Standard deviation of shocks σ_ν^2, σ_A^2	0.10
Autoregressive parameter ρ^ν, ρ^A	0.60

that, while the level of the moments changes with these parameters, it does not affect the ordinal ranking between different steady states. Note that this means we cannot attach any quantitative interpretation to the results. We can only compare results qualitatively (i.e. ordinally).

3.2 Solution method and the risky steady state

The objective of the exercise in this Chapter is to find the risky steady state of the system. According to Coeurdacier, Rey and Winant (2011), the risky, or stochastic, steady state is the point where “agents choose to stay at a given date if they expect future risk and if the realisation of shocks is zero at this date”. It is the steady state but adjusted to account for perceptions of future risk. So in the risky steady state, consumption, for instance, will typically be lower (compared to in the deterministic non-stochastic steady state) due to precautionary saving.

Why do we solve for the risky steady state (as opposed to just finding the deterministic

non-stochastic steady state)? The rationale is three-fold. First, it is clear from equation (7) that the bank's portfolio allocation depends on the perceptions of risk in the economy (specifically, the variances and covariances of asset returns and funding costs). The bank's portfolio decision also affects the risk spread and hence bank leverage as well. So, in order to compute these variables of interest, we need to find the risky steady state that pins down these perceptions of risk (i.e. second-order moments). Second, because the household is risk-averse, a proper comparison of welfare between outcomes ought to take into account the riskiness of household consumption, which is something that the deterministic steady state ignores. Finally, our ultimate aim is to consider exchange rate volatility ($\text{Var}(E)$) and this method allows us to compute this moment easily.

Following Gertler, Kiyotaki and Queralto (2012), we solve for the risky steady state using an iterative method. First, we take a second-order approximation of the model. For some initial guess of the second-order moments of the system, these approximations allow us to calculate the risky steady state. Second, we take a first-order approximation of the model around this risky steady state. Given the initial set of risky steady state values, this linear system allows us to calculate a new set of second-order moments. We repeat this process until the values of second-order moments and the risky steady state converge on a fixed point. See Appendix 1 for details.

In order to make a fair comparison between the two policies, we set the policy intensity parameters (λ, κ) so as to maximise social welfare. That is, we compare the optimal version of one policy with the optimal version of the other. We need some expression for household and social welfare. Following Faia and Monacelli (2007) and Gertler and

Karadi (2011), we write the household utility function⁸ in recursive form

$$\begin{aligned} W_t &= \log(C_t) + \beta \mathcal{E}_t(W_{t+1}) \\ &= \log(C_t) + \beta \mathcal{E}_t(\log(C_{t+1})) + \beta^2 \mathcal{E}_t(\log(C_{t+2})) + \beta^3 \mathcal{E}_t(\log(C_{t+3})) + \dots \end{aligned}$$

Taking a second-order approximation of this expression, we can find household welfare in the risky steady state (a $\sim$ denotes the risky steady state level of the variable)

$$\begin{aligned} \widetilde{W} &= \log(\widetilde{C}) + \beta \log(\widetilde{C}) + \beta^2 \log(\widetilde{C}) + \beta^3 \log(\widetilde{C}) + \dots \\ &\quad + \beta \frac{\text{Var}_t(C)}{2\widetilde{C}^2} + \beta^2 \frac{\text{Var}_t(C)}{2\widetilde{C}^2} + \beta^3 \frac{\text{Var}_t(C)}{2\widetilde{C}^2} + \beta^4 \frac{\text{Var}_t(C)}{2\widetilde{C}^2} + \dots \\ &= \frac{\log(\widetilde{C})}{1-\beta} + \beta \frac{\text{Var}(C)}{1-\beta} \frac{1}{2\widetilde{C}^2} \end{aligned}$$

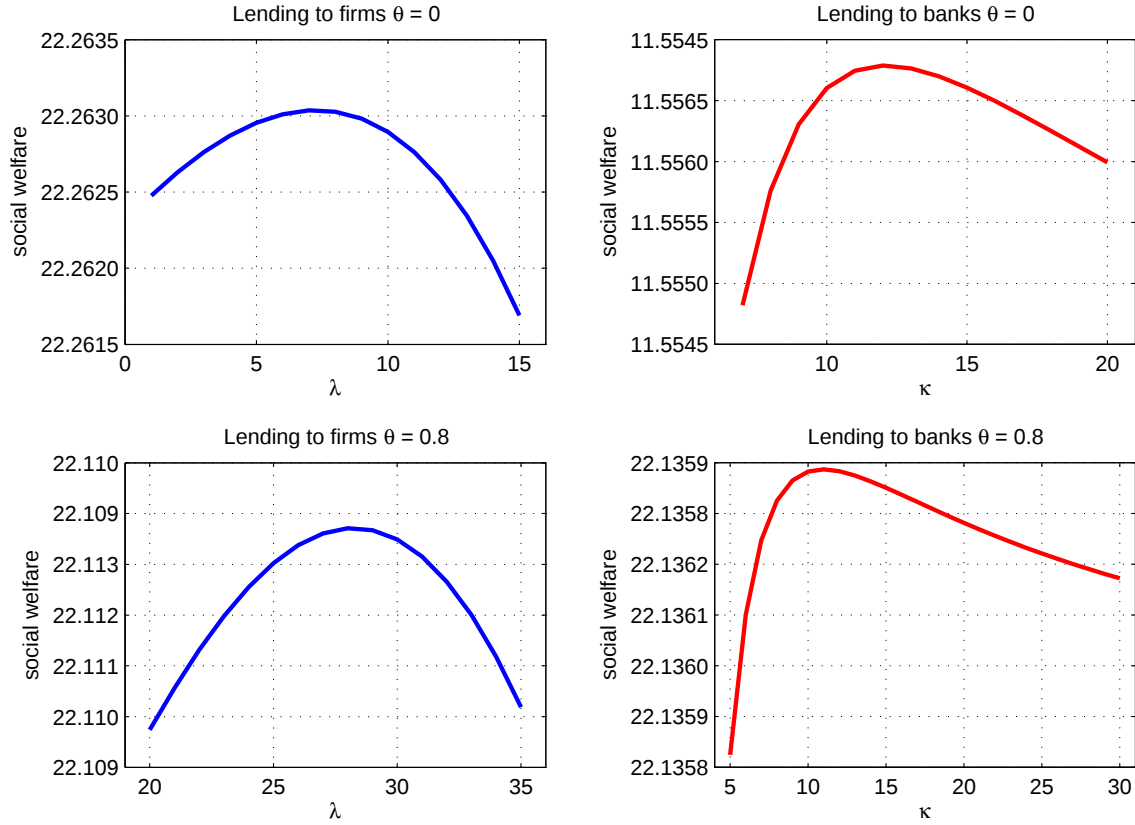
Also following Gertler and Karadi (2011), we assume that government credit policy carries a deadweight cost τX_t because the government is less efficient at intermediating funds than the private sector. We set $\tau = 0.5$. A different value for τ would affect the cardinal levels of the computed moments, but not the relative ordinal ranking between different steady states. Social welfare is given by household utility net of efficiency costs

$$S_t = \log(C_t) - \tau X_t + \beta \mathcal{E}_t(S_{t+1})$$

and so by the same procedure above, in the risky steady state, social welfare (i.e. welfare net of efficiency costs) is given by

$$\widetilde{S} = \frac{\log(\widetilde{C})}{1-\beta} - \frac{\tau \widetilde{X}}{1-\beta} + \beta \frac{\text{Var}(C)}{1-\beta} \frac{1}{2\widetilde{C}^2}$$

⁸As in Chapters 1 and 2, we assume log-utility with respect to consumption. We abstract from disutility of labour since it is fixed at one under all scenarios.

Figure 1: Social welfare as policy intensity (λ, κ) varies

In figure 1 we plot social welfare as a function of the policy intensity parameters. We then take the values of λ and κ that maximise welfare in each respective scenario and compare the risky steady states under each of these optimal policies. For instance, when $\theta = 0$, we use the optimal values $\lambda = 7, \kappa = 12$.

3.3 Credit policy where $\theta = 0$

Consider, first, the case where $\theta = 0$. This is the case where the banking sector can only obtain funding from foreign depositors (e.g. Gertler, Gilchrist and Natalucci, 2007). This may arise in a country where financial markets and domestic savings are

insufficiently deep to fund capital investment. The risky steady states of the three scenarios of interest are presented in table 2.

In the left-hand column, we consider the case of no policy. The bank allocates a small proportion of its portfolio $\tilde{\alpha}$ to the home asset. The bank is hedging against foreign borrowing costs by holding a relatively large proportion of its portfolio in the foreign asset (recall equation (7)). Note that consumption is lower in the risky steady state than in the non-stochastic deterministic steady state (1.2578 vs. 1.2609). This represents the fact that, when risk perceptions become relevant in the risky steady state, households undertake precautionary saving. Furthermore, the risk spread is higher (0.0056 vs. 0.0050), reflecting the fact that banks engage in less risk-taking (i.e. they buy and hold fewer risky assets) and so they are less able to take advantage of the arbitrage opportunities available in the risky asset market.

In the middle column, we consider the policy where the government extends credit to the goods-producing sector according to the rules in equations (24) and (25). The government essentially props up demand for the home asset in the event of a negative shock. Because of government support for the home asset, the home price of capital Q (and thus the return on the home asset R_E) falls by less in the event of a negative shock. The bank thus allocates a larger proportion of its portfolio $\tilde{\alpha}$ to the home asset. Higher overall demand for the home asset translates into higher investment demand which means that the home capital stock $\tilde{K}$ and output are also greater. The level of household consumption does not change in the risky steady state (the size of the government intervention is small). However, because this policy mitigates the effect of shocks on Q (and thus on R_E and other variables), the variances of consumption and the exchange rate edge down compared with the no-policy case. This results in increases in household welfare $\tilde{U}$.

In the right-hand column, we consider the policy where the government extends credit to the banking sector according to the rules in equations (27) and (28). The government essentially partially re-capitalises the bank in the event of a negative shock. Because the bank is now directly supported by government policy, it is prepared to engage in greater risk-taking and so allocates a much larger proportion of its portfolio $\tilde{\alpha}$ to the home asset⁹. As a result, investment demand is much higher, resulting in even higher capital and output. The effect of each unit of government credit on the home capital stock ($\frac{\Delta \tilde{K}}{\tilde{X}}$) is greater under this policy than in the policy where the government directly invests in the goods-producing firm. This is because for one unit of credit extended to the bank, the bank can extend more than one unit of credit to the goods-producing sector through raising its leverage (Céspedes, Chang and Velasco 2012). Because the bank engages in greater risk-taking (i.e. it buys and holds more risky assets), it exhausts more arbitrage opportunities in asset markets, leading to a smaller risk spread $\widetilde{R}_E - \tilde{R}$. A higher capital stock thus leads to an even higher level of consumption $\tilde{C}$.

However, this policy is costly. Because it encourages banks to undertake greater risk-taking (i.e. to buy more risky assets for any given size of bank net worth), bank leverage $\frac{\tilde{D}}{\tilde{N}_B}$ rises. This means that in the event of a negative shock, the required adjustment of financial sector variables will be greater. In particular, the risk premium will rise by more and (recall Chapter 3) this will mean a larger jump in the exchange rate. Accordingly, under this policy, the variance of the exchange rate $\text{Var}(E)$ is substantially higher and so the variance of consumption $\text{Var}(C)$ is also much higher (because E is the price of imports). The effect of this rise in variance is so high that household welfare is actually lower under this policy than in the no-policy case.

In summary, credit policy is effective in raising consumption and output. Credit policy

⁹That is, the bank becomes willing to hedge less against risks to foreign borrowing costs.

aimed at banks is even more effective in this respect because banks can lever up on each unit of credit they receive. However, targeting banks is a costly policy because it raises bank leverage, which increases the variances of consumption and the exchange rate.

To be clear, it would be wrong to interpret the cost associated with the policy of lending to banks as an accidental side-effect. The relative advantage and disadvantage of the policy of lending to banks stem from the same effect. To elaborate, rearrange equation (29), which defines the leverage that the bank can obtain from depositors for any given spread between bank earnings and the riskless rate

$$\frac{D}{N_B} \equiv \text{private leverage} = \left(1 + \frac{X}{N_B}\right) \frac{(1 - \mu) \frac{R^{bank}}{R}}{1 - (1 - \mu) \frac{R^{bank}}{R}} \quad (34)$$

As we know, and as (34) makes clear again, as the spread between bank earnings and the riskless rate rises $\frac{R^{bank}}{R} \uparrow$, the leverage that the bank can obtain from private depositors unambiguously rises. What (34) also shows is that if the government pursues the policy of lending support to banks (i.e. $X > 0$), then, for any given spread $\frac{R^{bank}}{R}$, the bank can obtain a higher ratio of leverage from private depositors.

This is because private depositors treat the government's capital injection into banks as part of the collateral that banks can pledge in the loan contracts between banks and depositors. This is because banks cannot abscond with any of the emergency loan that the government has extended (unlike the credit that the depositors have supplied) and so this government assistance to the bank is viewed as part of the bank's "internal capital". This is a result of our assumption that governments can enforce their loans with banks so effectively that banks always repay the government, even if they default on their contracts with private depositors.

Hence, if governments support banks, banks can achieve a higher degree of leverage from private lenders. Now, this is clearly an advantage. This policy allows banks to increase leverage, therefore increasing the supply of financial intermediation and increasing the level of investment in the economy. This is exactly why this policy is more effective than the policy of simply lending to goods-producing firms. However, this is also why this policy is costly. It is exactly because this policy allows banks to increase private leverage that raises the volatility of the system. Hence the deliberate advantage of this policy is also its own shortcoming.

3.4 Credit policy where $\theta = 0.8$

To check our results in the previous section for robustness of the choice of θ , we also consider the case of $\theta = 0.8$ (i.e. bank debt is 80% home-denominated). This reflects Australian data (specifically the 2000-7 domestic share of liabilities of commercial banks). The results are presented in table 3. Again, in order to make a fair comparison between policies, we choose the policy parameter to maximise welfare under each policy scenario.

In the left-hand column, we present the risky steady state for the no policy base case. Notice that the proportion of the bank's portfolio held in home assets $\tilde{\alpha}$ is much higher when $\theta = 0.8$ compared with when $\theta = 0$, reflecting the fact that the bank is hedging less against foreign borrowing costs since a much smaller proportion of its liabilities is now foreign-denominated (recall our discussion of equation (7)).

In the middle column, we again consider the policy of government extending credit to the goods-producing sector directly. For the same reasons above (i.e. for $\theta = 0$), $\tilde{\alpha}$ and $\tilde{K}$ are higher, $\text{Var}(C)$ and $\text{Var}(E)$ are lower, and so household welfare $\tilde{U}$ is higher.

In the right-hand column, we again consider the policy of government extending credit to banks. For the same reasons above (i.e. for $\theta = 0$): $\widetilde{K}$ is higher; lending to banks is more effective at raising output than lending to firms (per unit of government intermediation); consumption $\widetilde{C}$ is higher; but greater bank risk-taking leads to higher leverage $\frac{\widetilde{D}}{\widetilde{N}_B}$ and so higher variances of consumption and the exchange rate (compared with the other policy of lending to firms), which weighs down on household welfare. The cost of this policy is not as pronounced as in the case of $\theta = 0$: welfare under this policy is lower than welfare under the policy of lending to firms, but nonetheless higher than in the no-policy case.

Table 2: Risky steady states for $\theta = 0$

		No policy	Lend to firms ($\lambda = 7$)	Lend to banks ($\kappa = 12$)
government intermediation	$\widetilde{X}$	-	0.0133	0.0590
as % of GDP	$\frac{\widetilde{X}}{\widetilde{Y}}$	-	0.75%	3.31%
bank portfolio at home	$\widetilde{\alpha}$	0.1857	0.1862	0.6669
capital stock (and output)	$\widetilde{K}$	15.2046	15.2053	15.5712
policy effect on output	$\frac{\Delta \widetilde{K}}{\widetilde{X}}$	-	0.0660	6.2136
risk spread	$\widetilde{R}_E - \widetilde{R}$	0.0056	0.0056	0.0049
consumption	$\widetilde{C}$	1.2578	1.2578	1.2617
bank leverage	$\frac{\widetilde{D}}{\widetilde{N}_B}$	3.0616	3.0616	3.1170
consumption variance	$\text{Var}(\widetilde{C})$	0.0214	0.0212	0.3676
exchange rate variance	$\text{Var}(\widetilde{E})$	0.0134	0.0133	0.2312
household utility	$\widetilde{W}$	22.2691	22.2743	11.8102

Table 3: Risky steady states for $\theta = 0.8$

		No policy	Lend to firms ($\lambda = 28$)	Lend to banks ($\kappa = 11$)
government intermediation	$\widetilde{X}$	-	0.0445	0.0225
as % of GDP	$\frac{\widetilde{X}}{\widetilde{Y}}$	-	2.50%	1.27%
bank portfolio at home	$\widetilde{\alpha}$	0.6472	0.6553	0.6381
capital stock (and output)	$\widetilde{K}$	15.5153	15.5220	15.5272
policy effect on output	$\frac{\Delta \widetilde{K}}{\widetilde{X}}$	-	0.1506	0.5286
risk spread	$\widetilde{R}_E - \widetilde{R}$	0.0050	0.0050	0.0049
consumption	$\widetilde{C}$	1.2611	1.2611	1.2612
bank leverage	$\frac{\widetilde{D}}{\widetilde{N}_B}$	3.0600	3.0599	3.0820
consumption variance	$\text{Var}(\widetilde{C})$	0.0348	0.0309	0.0331
exchange rate variance	$\text{Var}(\widetilde{E})$	0.0219	0.0194	0.0208
household utility	$\widetilde{W}$	22.1129	22.2397	22.1730

3.5 Dynamic effects of credit policy

Finally, we consider the dynamic effects of credit policy in response to a net worth shock by simulating the linear approximation of the model around the risky steady state. These responses generally corroborate the conclusions drawn from the analysis of risky steady states above. We simulate a 10% temporary persistent shock to bank net worth ν under the three scenarios outlined in table 3 with $\theta = 0.8$. The responses are presented in figure 2 as deviations from the risky steady state of each scenario. As in Chapter 3, the system takes a long time to return to steady state (~ 10 years) due to the time required to deleverage and re-leverage. In figure 2, we focus our attention on the first few time periods after the shock since the differences between the scenarios become less clear if we “zoom out” of the figure.

Consider the blue lines in figure 2, which represent the central case of no policy. In response to the shock, *bank net worth* falls. This immediately causes the *bank's leverage position* to worsen and in response creditors demand a higher *spread*. Depositors withdraw funding from home banks and crowd into the home riskless asset, causing the *home riskless rate* to fall. This occurs until the point where the spread between bank returns and the home riskless rate is high enough to entice depositors to keep funding home banks.

Depositors also flood to the foreign riskless asset, leading to financial outflows that cause the *exchange rate* to depreciate. This depreciation occurs until the point where the subsequent per-period appreciation raises the spread between bank earnings and the foreign riskless rate by the necessary amount to keep depositors satisfied with funding home banks. Hence the exchange rate initially depreciates so as to subsequently appreciate, as we showed in Chapter 3. And because depositors treat home and foreign riskless assets as perfect substitutes *ex ante* (i.e. UIP holds), the extent to which

home and foreign riskless rates fall (in a common currency) is equal. Unsurprisingly, the spreads on bank returns above home and foreign riskless rates are the same in expectation (in a common currency).

Bank demand for home assets falls and hence the *price of capital* and *investment* fall. *Capital* and thus *output* follow the price of capital. *Consumption* follows the path of the riskless rate.

The red lines represent the policy whereby government extends credit directly to goods-producing firms. The policy essentially raises demand for the home asset, dampening the fall in the price of capital. This implies a smaller fall in investment, output, and consumption. Banks make a larger loss (because they hold a larger share of their portfolio in the loss-making home asset) but overall bank leverage is better under this policy because government intermediation of credit to firms means that banks do not have to borrow so much in order to fund the existing stock of capital (i.e. the burden of buying risky firm-issued assets shifts from the bank to the government). Hence the risk spread is lower under this policy and the exchange rate depreciates by less after the shock.

This policy thus supports the exchange rate, dampening its initial depreciation after shocks. We can interpret this kind of policy as a kind of exchange rate intervention: the government expends its foreign reserves to support the domestic currency by purchasing domestic assets. This is significant because it decreases the extent to which banks suffer negative “balance sheet effects” after an unanticipated depreciation and, furthermore, it dampens the rise in the price of imported goods for households.

The dashed black lines represent the policy whereby the government extends credit to banks. Similarly, this policy has positive effects on output by encouraging banks to take risk (i.e. to invest in risky assets in firms). As discussed above, it has a larger

proportional effect on dampening the fall in output because banks can supply greater than one unit of intermediation (through leverage) for every unit of credit extended to them by the government. Thus, even though the size of this government intervention is smaller (by around a factor of 3), the effect of this intervention on capital and output is comparable to the effect of the policy of lending to the goods-producing sector.

Lending to banks, however, entails other non-trivial costs. Because governments support banks, bank leverage rises by more. This is due to the effect we discussed above and was made clear by equation (34). Private depositors treat the government's capital injection into banks as part of the collateral that banks can pledge in the loan contracts between banks and depositors. Hence the policy of governments lending to banks enables banks to achieve a higher degree of leverage from private depositors. As discussed previously, this is how the benefits of this policy arise. By allowing bank leverage to rise by more, this policy raises the quantity of financial intermediation in the economy.

However, this is also why this policy is costly. It is exactly because this policy allows banks to increase private leverage that raises the volatility of the system. This higher volatility is transmitted to the rest of the economy via the risk spread. Because bank leverage is higher under policy, this means that the required spread between bank earnings and riskless rates also rises by more (compared with the policy of lending to firms).

A higher rise in the spread thus implies a greater fall in the home riskless rate under this policy compared with the other policy. This is achieved by a greater fall in aggregate consumption (higher net saving on part of the representative household).

A higher rise in the spread (relative to the foreign riskless rate) also means that the exchange rate must experience a larger per-period appreciation along the adjustment path and so the initial depreciation of the exchange rate is also greater with this policy

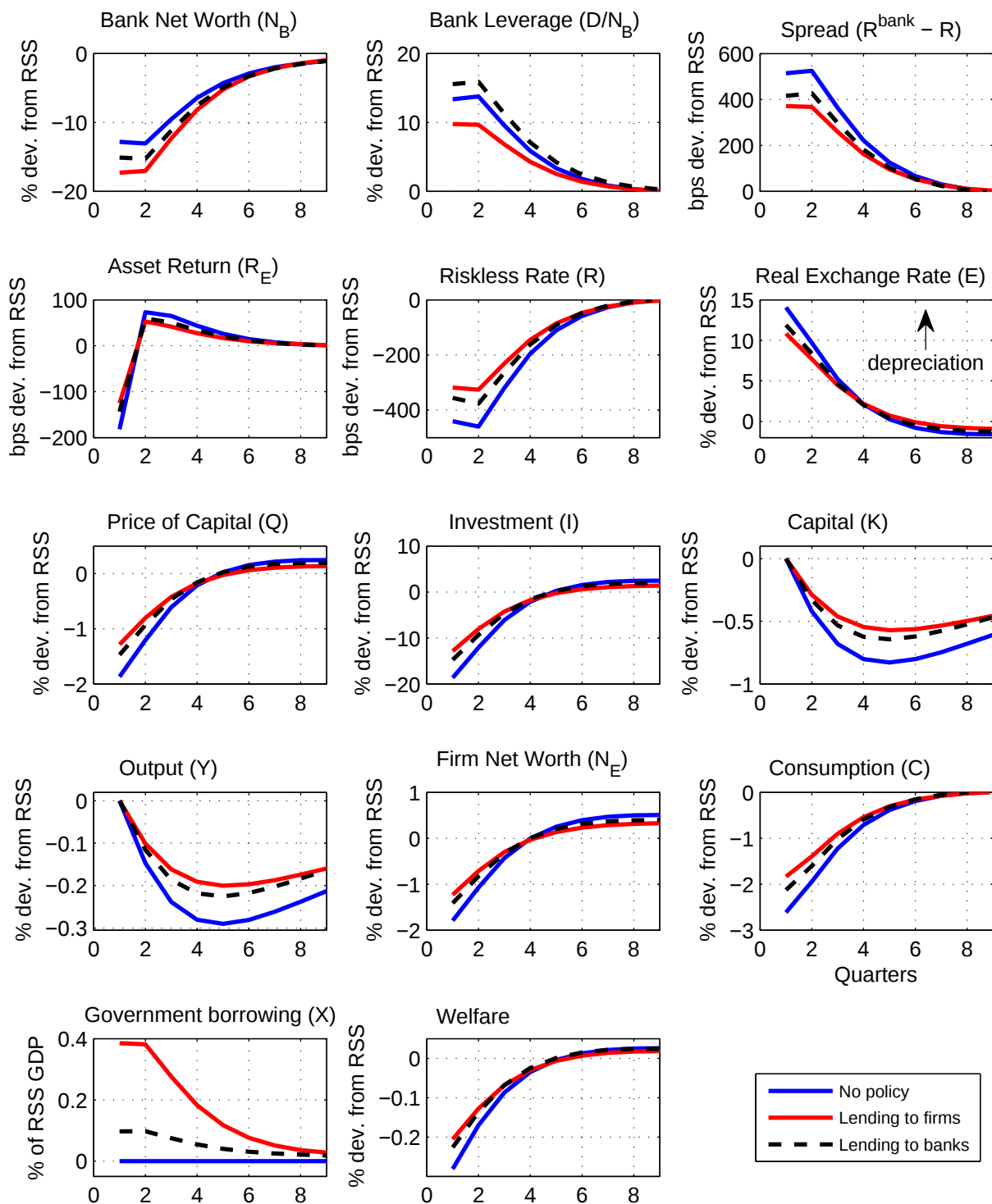
(of lending to banks) than with the other policy (of lending to firms). Thus depositors withdraw from home banks by more, causing the exchange rate to initially depreciate by more. Hence home consumption also falls by more as a result of the price of imports rising by more.

This supports the finding in sections 3.3 and 3.4 that the policy of lending to banks raises output, but increases the volatility of the exchange rate and consumption due to higher risk-taking on part of banks *ceteris paribus*. Notice though that (similar to in section 3.4) while volatility under this policy is higher than under the policy of lending to firms, it is still lower than in the no policy case.

So, in the bottom left panel of figure 2 we see that household welfare¹⁰ is higher with policy than without, with lending to firms slightly dominating lending to banks.

¹⁰Defined in the same way as above $\text{Welfare}_t = \text{Utility}_t + \beta \mathcal{E}_t (\text{Welfare}_{t+1})$. In other words, welfare this period is the net present value of the utility from consumption in all future periods.

Figure 2: Simulation of a net worth shock



4 Concluding remarks

This Chapter performed a simple policy exercise in order to examine the effect of unconventional credit policy on a small open economy with financial frictions, similar to that developed at length in Chapter 3. We draw the following conclusions from the results in the previous section

1. Unconventional credit policy has a positive effect on domestic output and consumption. Lending to home firms supports the price of capital while lending to banks supports risk-taking by the financial sector. Both of these contribute to higher investment demand and so result in higher levels of capital, output, and consumption. Lending to banks is more effective than lending to firms in this respect because for each unit of government credit supplied, banks can supply more than one unit of intermediation to the goods-producing sector through leverage. In the open economy, credit policy also supports the exchange rate by decreasing the extent to which it initially depreciates after negative financial shocks.
2. However, lending to banks is a policy that entails non-trivial costs. It encourages banks to engage in more risk-taking by allowing them to borrow more from private lenders. This raises bank leverage, which increases the volatility of the system. Hence, compared with the policy of lending to firms, this policy leads to higher variances of key variables including the exchange rate and consumption. In some cases, this policy may even lead to lower welfare than in the no-policy case. We interpret this as illustrative of the problem of moral hazard caused by a policy of lending support to failing banks.

These results extend the well-established findings of the closed economy literature to the open economy and the exchange rate. Christiano and Ikeda (2012) stress the positive

effects of credit policy in the presence of financial frictions. Moreover, Gertler, Kiyotaki and Queralto (2012) document the negative consequences of credit policy associated with moral hazard. In their model, anticipated policy leads to banks holding smaller buffers of outside equity that, analogous to our model, lead to higher bank leverage. The way they interpret the problem in terms of a commitment issue is useful. Governments cannot credibly commit not to intervene in the event of a crisis and the *ex post* benefits of intervention are even higher if bank leverage is worse, which increases the incentive to intervene even more. Thus it is rational for banks to anticipate credit policy, leading to higher risk exposure. In the open economy, this problem of moral hazard leads to higher volatility of the exchange rate, which is welfare-deteriorating because of its effect on the price of imported goods and also because of its effect on the value of bank net worth relative to foreign debt.

There are possible extensions to this analysis. As mentioned in the introduction, we have only considered credit policy. It would be useful to extend the analysis to cover the more prominent form of unconventional policy that has been practised of late (especially in developed markets), unconventional monetary policy (QE). Given the findings of Gertler and Karadi (2011) in a closed economy, we would expect the result (1) above to apply to QE as well. In an open economy setting, QE could operate via another possible channel: monetary easing would cause the nominal exchange rate to depreciate, leading to higher inflation as this depreciation passed through to domestic prices. It would be interesting to see how important this channel is. This is a timely concern, given worries about the deflationary effect of a strong currency on the Euro area¹¹.

¹¹See transcript of statement and Q&A by ECB President Draghi following Governing Council meetings in March, April, and May 2014.

References

- [1] Aghion, Philippe, Philippe Bacchetta, & Abhijit Banerjee. 2004. A corporate balance-sheet approach to currency crises. *Journal of Economic Theory* 119 (1): 6—30.
- [2] Benford, James, Stuart Berry, Kalin Nikolov, & Chris Young. 2009. Quantitative Easing. *Quarterly Bulletin* (2009 Q2: 90—100), Bank of England.
- [3] Bernanke, Ben S., Mark Gertler & Simon Gilchrist. 1999. The financial accelerator in a quantitative business cycle framework. In *Handbook of Macroeconomics* 1 (1), edited by John B. Taylor & Michael Woodford. Elsevier.
- [4] Cespedes, Luis F., Roberto Chang, & Javier Garcia-Cicco. 2011. Heterodox central banking. In *Monetary Policy under Financial Turbulence* (chapter 8: 219—81), first edition, edited by Luis F. Cespedes, Roberto Chang & Diego Saravia. Central Bank of Chile.
- [5] Cespedes, Luis F., Roberto Chang, & Andres Velasco. 2012. Financial intermediation, exchange rates, and unconventional policy in an open economy. NBER Working Papers 18431. National Bureau of Economic Research.
- [6] ———. 2013. Is inflation targeting still on target? The recent experience of Latin America. Research Department Publications IDB-WP-384. Inter-American Development Bank, Research Department.
- [7] Chari, Varadarajan V. & Patrick J. Kehoe. 2013. Bailouts, time inconsistency, and optimal regulation. NBER Working Papers 19192. National Bureau of Economic Research.
- [8] Chen, Han, Vasco Curdia, & Andrea Ferrero. 2012. The macroeconomic effects of large-scale asset purchase programmes. *Economic Journal* 122 (564): F289—F315.
- [9] Christensen, Jens H. E. & Glenn D. Rudebusch. 2012. The response of interest rates to U.S. and U.K. quantitative easing. Federal Reserve Bank of San Francisco Working Paper Series 2012-06, Federal Reserve Bank of San Francisco.
- [10] Christiano, Lawrence J. & Daisuke Ikeda. 2012. Government policy, credit markets and economic activity. NBER Working Papers 17142, National Bureau of Economic Research.
- [11] Coeurdacier, Nicolas, Helene Rey, & Pablo Winant. 2011. The risky steady state. *American Economic Review* 101 (3): 398—401.
- [12] Craig, Ben & Valeriya Dinger. 2010. A microeconomic investigation into bank interest rate rigidity. Working Paper 10-01. Federal Reserve Bank of Cleveland.

- [13] ———. 2013. Uncertainty and bank wholesale funding. Discussion Paper No. 39/2013. Deutsche Bundesbank.
- [14] Curdia, Vasco & Michael Woodford. 2011. The central-bank balance sheet as an instrument of monetary policy. *Journal of Monetary Economics* 58 (1): 54—79.
- [15] Dinger, Valeriya. 2011. Bank mergers and deposit interest rate rigidity. Working Paper 11-31. Federal Reserve Bank of Cleveland.
- [16] Faia, Ester & Tommaso Monacelli. 2007. Optimal interest rate rules, asset prices, and credit frictions. *Journal of Economic Dynamics and Control* 31 (10): 3228—3254.
- [17] Farhi, Emmanuel & Jean Tirole. 2012. Collective moral hazard, maturity mismatch, and systemic bailouts. *American Economic Review* 102 (1): 60—93.
- [18] Gali, Jordi & Tommaso Monacelli. 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies* 72: 707—34.
- [19] Gertler, Mark, Simon Gilchrist & Fabio Natalucci. 2007. External constraints on monetary policy and the financial accelerator. *Journal of Money, Credit and Banking* 39 (2—3): 295—330.
- [20] Gertler, Mark & Peter Karadi. 2011. A model of unconventional monetary policy. *Journal of Monetary Economics* 58 (1): 17—34.
- [21] Gertler, Mark & Nobuhiro Kiyotaki. 2010. Financial intermediation and credit policy in business cycle analysis. In *Handbook of Monetary Economics* 3 (chapter 11), first edition, edited by Benjamin M. Friedman & Michael Woodford. Elsevier.
- [22] Gertler, Mark, Nobuhiro Kiyotaki & Albert Queralto. 2012. Financial crises, bank risk exposure and government financial policy. *Journal of Monetary Economics* 59 (2012 supplement issue): S17—S34.
- [23] Jarrow, Robert A. & Hao Li. 2012. The impact of quantitative easing on the U.S. term structure of interest rates. 2012. Johnson School Research Paper No. 2-2012, Cornell University.
- [24] Joyce, Michael, Matthew Tong, & Robert Woods. 2011. The United Kingdom’s quantitative easing policy: design, operation and impact. *Quarterly Bulletin* (2011 Q3: 200—12), Bank of England.
- [25] Kiyotaki, Nohubiro & John Moore. 1997. Credit cycles. *Journal of Political Economy* 105 (2): 211—48.
- [26] Luk, Sheung Kan & David Vines. 2011. Financial-friction macroeconomics with highly leveraged financial institutions. CEPR Discussion Papers 8576. Centre for Economic Policy Research.

- [27] Sa, Filipa & Francesca Viani. 2013. Shifts in portfolio preferences of international investors: an application to sovereign wealth funds. *Review of International Economics* 21 (5): 868—85.
- [28] Schmitt-Grohe, Stephanie & Martin Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61 (1): 163—85.
- [29] Sharpe, Steven A. 1997. The effect of consumer switching costs on prices: a theory and its application to the bank deposit market. *Review of Industrial Organization* 12: 79—94.
- [30] Ueda, Kozo. 2012. Banking globalization and international business cycles: cross-border chained credit contracts and financial accelerators. *Journal of International Economics* 86 (1): 1—16.

Appendix

1 Finding the risky steady state

We follow the method developed by Coeurdacier, Rey and Winant (2011) (and subsequently applied by Gertler, Gilchrist and Queralto [2012]). By using (12), (14), (15), (19), (20), and (21) to eliminate, respectively $\{Y, w^E, w^B, P, C_H, C_H^*\}$, we condense the no-policy model (4)-(22) to the following system

$$\frac{D_t}{(N_{Bt} + D_t)} = (1 - \mu) \frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R}_E \frac{E_{t+1}}{E_t} \right)}{R_{t+1}} \quad (35)$$

$$\frac{D_t}{(N_{Bt} + D_t)} = (1 - \mu) \frac{\mathcal{E}_t \left(\alpha_t R_{Et+1} + (1 - \alpha_t) \overline{R}_E \frac{E_{t+1}}{E_t} \right)}{\mathcal{E}_t \left(\overline{R} \frac{E_{t+1}}{E_t} \right)} \quad (36)$$

$$\alpha_t (N_{Bt} + D_t) + D_t^* = Q_t K_{t+1} - N_{Et} \quad (37)$$

$$\alpha_t = \frac{\mathcal{E}_t \left(R_{Et+1} - \overline{R_E} \frac{E_{t+1}}{E_t} \right) + \begin{pmatrix} \text{Var} \left(E_{t+1} \right) \frac{\overline{R_E}}{E_t} \\ -\text{Cov} \left(R_{Et+1}, E_{t+1} \right) \end{pmatrix} \left(\frac{(N_{Bt} + D_t) \overline{R_E} - D_t (1 - \theta) \overline{R}}{E_t} \right)}{(N_{Bt} + D_t) \begin{pmatrix} \text{Var} \left(R_{Et+1} \right) + \left(\frac{\overline{R_E}}{E_t} \right)^2 \text{Var} \left(E_{t+1} \right) \\ - 2 \frac{\overline{R_E}}{E_t} \text{Cov} \left(R_{Et+1}, E_{t+1} \right) \end{pmatrix}} \quad (38)$$

$$N_{Bt} = \nu_t \gamma^B \begin{pmatrix} \left(\alpha_{t-1} R_{Et} + (1 - \alpha_{t-1}) \overline{R_E} \frac{E_t}{E_{t-1}} \right) (N_{Bt-1} + D_{t-1}) \\ - D_{t-1} \left(\theta R_t + (1 - \theta) \overline{R_E} \frac{E_t}{E_{t-1}} \right) \end{pmatrix} + \nu_t (1 - \phi) \Omega_B A_t K_t^\phi \quad (39)$$

$$K_{t+1} = (1 - \delta) K_t + I_t - \frac{\xi (K_{t+1} - K_t)^2}{2 K_t} \quad (40)$$

$$Q_t = 1 - \xi + \xi \frac{K_{t+1}}{K_t} \quad (41)$$

$$R_{Et} = \frac{1}{Q_{t-1}} \left((1 - \delta) Q_t + \phi A_t K_t^{\phi-1} \right) \quad (42)$$

$$N_{Et} = \gamma^E R_{Et} N_{Et-1} + (1 - \phi) \Omega_E A_t K_t^\phi \quad (43)$$

$$1 = \mathcal{E}_t \left(\frac{C_t R_{t+1}}{C_{t+1}} \right) \beta \quad (44)$$

$$A_t K_t^\phi = \gamma C_t \left(\gamma + (1 - \gamma) E_t^{1-\eta} \right)^{\frac{\eta}{1-\eta}} + \overline{C^*} E_t^\eta + I_t + \left(1 - \gamma^E \right) R_{Et} N_{Et-1} + \left(1 - \gamma^B \right) \frac{N_{Bt} - (1 - \phi) \Omega_B A_t K_t^\phi}{\gamma^B} \quad (45)$$

$$\log (A_t / \overline{A}) = \rho^A \log (A_{t-1} / \overline{A}) + \epsilon_t^A \quad (46)$$

$$\log (\nu_t) = \rho^\nu \log (\nu_{t-1}) + \epsilon_t^\nu \quad (47)$$

We take a second-order approximation of this system around each variable's expected future value. We evaluate expectational terms at the risky steady state to get the following system ($\overline{Z}$ denotes deterministic steady state, $\widetilde{Z}$ denotes risky steady state)

$$\frac{\widetilde{D}}{(\widetilde{N_B} + \widetilde{D})} = (1 - \mu) \frac{\widetilde{\alpha} \widetilde{R_E} + (1 - \widetilde{\alpha}) \overline{R_E}}{\widetilde{R}} \quad (48)$$

$$\frac{\widetilde{D}}{(\widetilde{N_B} + \widetilde{D})} = (1 - \mu) \frac{\widetilde{\alpha} \widetilde{R_E} + (1 - \widetilde{\alpha}) \overline{R_E}}{\widetilde{R}} \quad (49)$$

$$\tilde{Q}\tilde{K} - \tilde{N}_E = \tilde{\alpha}(\tilde{N}_B + \tilde{D}) + \tilde{D}^* \quad (50)$$

$$\tilde{\alpha} = \frac{\tilde{R}_E - \overline{R}_E + \begin{pmatrix} \text{Var}(E_{t+1}) \frac{\overline{R}_E}{E} \\ -\text{Cov}(R_{Et+1}, E_{t+1}) \end{pmatrix} \left(\frac{(\tilde{N}_B + \tilde{D})\overline{R}_E - \tilde{D}(1-\theta)\overline{R}}{\tilde{E}} \right)}{(\tilde{N}_B + \tilde{D}) \begin{pmatrix} \text{Var}(R_{Et+1}) + \left(\frac{\overline{R}_E}{E}\right)^2 \text{Var}(E_{t+1}) \\ -2\frac{\overline{R}_E}{E} \text{Cov}(R_{Et+1}, E_{t+1}) \end{pmatrix}} \quad (51)$$

$$\tilde{N}_B = \gamma^B \begin{pmatrix} (\tilde{\alpha}\tilde{R}_E + (1-\tilde{\alpha})\overline{R}_E)(\tilde{N}_B + \tilde{D}) \\ -\tilde{D}(\theta\tilde{R} + (1-\theta)\overline{R}) \end{pmatrix} + (1-\phi)\Omega_B\overline{A}\tilde{K}^\phi \quad (52)$$

$$\tilde{K} = (1-\delta)\tilde{K} + \tilde{I} \quad (53)$$

$$\tilde{Q} = 1 \quad (54)$$

$$\tilde{R}_E = \frac{1}{\tilde{Q}}((1-\delta)\tilde{Q} + \phi\overline{A}\tilde{K}^{\phi-1}) \quad (55)$$

$$N_{Et} = \gamma^E \tilde{R}_E \tilde{N}_E + (1-\phi)\Omega_E\overline{A}\tilde{K}^\phi \quad (56)$$

$$0 = \beta\tilde{R} - 1 + \frac{\beta\tilde{R}\text{Var}(C_{t+1})}{\tilde{C}^2} \quad (57)$$

$$\begin{aligned} \overline{A}\tilde{K}^\phi &= \gamma\tilde{C}(\gamma + (1-\gamma)\tilde{E}^{1-\eta})^{\frac{\eta}{1-\eta}} + \overline{C}^*\tilde{E}^\eta + \tilde{I} \\ &+ (1-\gamma^E)\tilde{R}_E\tilde{N}_E + (1-\gamma^B)\frac{\tilde{N}_B - (1-\phi)\Omega_B\overline{A}\tilde{K}^\phi}{\gamma^B} \end{aligned} \quad (58)$$

The system (48)-(58) gives us values of the risky steady state

$$\mathbf{S} = \{\tilde{\alpha}, \tilde{D}, \tilde{Q}, \tilde{K}, \tilde{I}, \tilde{N}_B, \tilde{N}_E, \tilde{R}_E, \tilde{R}, \tilde{E}, \tilde{C}\}$$

as a function of the second-order moments

$$\mathbf{M} = \{\text{Var}(E), \text{Var}(R_E), \text{Cov}(R_E, E), \text{Var}(C)\}$$

On the other hand, the linear dynamics of the system (35)-(47) around the risky steady state give us the second-order moments $\mathbf{M}$ as a function of the risky steady state $\mathbf{S}$.

The aim of the algorithm is to find a fixed point such that the mapping from $\mathbf{S}$ to $\mathbf{M}$ and from $\mathbf{M}$ to $\mathbf{S}$ yield the same values. This fixed point is found by starting with an initial guess for $\mathbf{S}$ and iterating forward until we converge on a fixed point.

2 A note on the θ parameter

The parameterisation of θ is not as strong an assumption as it appears. Ueda: “although the allocation of net worth used for borrowing from home and foreign lenders is exogenous, the allocation of borrowings between the two lenders is endogenously determined”. That is, what is exogenously set is how the bank allocates its net worth to home or foreign lenders. It remains the endogenous choice of banks to lever up on either part of their net worth as much as they wish, with the aim that their total borrowing is sufficiently large to make desired asset purchases. Indeed, we see that the parameter θ disappears from the equations describing bank borrowing (4)-(5).

Nonetheless, we can motivate the choice of an exogenous θ by assuming adjustment costs in changing sources of deposits. Craig and Dinger (2013) find that volumes of deposits are rigid due to adjustment costs (e.g. Sharpe, 1997). For any change in the assets of a bank, deposits typically adjust by only $\sim 7\%$ of the asset change. Craig and Dinger (2010) and Dinger (2011) find that, the larger the geographic scope of a bank, the slower its retail rates adjust in response to money market rates, an indication that sources of funding are rigid.

Conclusion

In this Conclusion, we summarise this thesis and discuss some possible extensions to the project as a whole. The objective of the thesis is to better understand real exchange rate determination, with a particular focus on the causes of exchange rate jumps. The predominant approach in the literature has been to examine the exchange rate volatility that arises when nominal shocks are propagated through a system with nominal rigidities. For instance, in Dornbusch (1976), an exogenous rise in the domestic money supply, combined with the slow adjustment of prices, causes real money balances to rise in the short run, hence lowering real interest rates relative to world rates and causing the home exchange rate to depreciate. The standard open economy model in the form of (for instance) Gali and Monacelli (2005) makes similar assumptions in an updated microfounded framework and the qualitative implications for the exchange rate are similar.

This thesis takes a slightly different approach. It explores, instead, the exchange rate volatility that arises from the interaction between real shocks and real rigidities. The simplest instance of this arises from a productivity shock in the presence of the slow adjustment of the capital stock. Because capital cannot adjust to its new long run level immediately, productivity shocks cause changes to the returns on holding capital and thus on the real interest rate at home. This leads to financial outflows or inflows that then affect the exchange rate.

In general, this means that in this thesis the consumption and household sides of the economy are modelled in the same way as in the standard open macroeconomic literature (Gali and Monacelli, 2005). Home and foreign goods are imperfectly substitutable and are aggregated using a constant elasticity of substitution index. The law of one price holds. Aggregate consumption follows an Euler equation. However, we abstract

from price and wage rigidities and focus instead on real rigidities. These include: the slow adjustment of the capital stock in production, as was emphasised by the real business cycle literature (Kydland and Prescott, 1982; Plosser, 1989); the imperfect substitutability of assets across borders (Sa and Viani, 2013; Meredith, 2007); frictions in credit contracts between lenders and borrowers (Bernanke, Gertler and Gilchrist, 1999; Gertler and Kiyotaki, 2010).

The rationale for this approach (covered in section 3.2 of the Introduction) is that there is some evidence in the empirical literature that real shocks and rigidities are important for explaining economic fluctuations and hence it is worthwhile to better understand the transmission of real shocks to the exchange rate. The aim of the project, then, is to get a better understanding how real rigidities and real shocks affect the exchange rate. More specifically, we want to understand whether these rigidities can generate significant jumps in the exchange rate following these types of shocks. If so, this would mean that we could offer a plausible additional explanation of exchange rate fluctuations, hence complementing the current monetary literature. Furthermore, we would be able to provide possible explanations of the large jumps in exchange rates that appear to be part of a medium to long run narrative in which short run cyclical shocks to monetary policy do not appear to play a significant role.

1 Summary of Chapters

Chapter 1 begins this thesis by building a model that represents our baseline. This model includes the slow adjustment of capital that is standard in RBC models. The model is otherwise frictionless. Financial capital is mobile across borders, as reflected by the assumption that the uncovered interest parity condition holds. We consider a negative shock to domestic aggregate productivity. The process by which the shock

transmits to the exchange rate is by now familiar. Because the domestic stock of capital cannot adjust to its long run equilibrium level immediately, the home real interest rate falls, leading to outflows of financial capital that place downward pressure on the exchange rate.

We show that the volatility implied by this transmission channel is reasonably small (when compared with the quantitative effect of the shock on output and when compared with the second order moments of real exchange rates observed in the data). The reason for this is that in this baseline model, because the UIP condition holds, the exchange rate only needs to move so as to equalise the common currency returns on home and foreign assets. In the presence of a time-varying price of capital (Tobin's Q), shocks to productivity generate comparably small changes in asset returns, and hence the burden of adjustment on the exchange rate is accordingly muted. The message of Chapter 1 is that we need more than just the slow adjustment of capital for real rigidities and shocks to generate significant exchange rate volatility.

The message of *Chapter 2* is that adding imperfect asset substitutability goes a little towards achieving this. In this Chapter, investors exhibit home asset bias. Our specification of home bias follows Meredith (2007), Kuralbayeva and Vines (2009), and Sa and Viani (2013). A preliminary finding of this Chapter is that a very parsimonious model can predict a plausible degree of home bias in asset allocations as long as we assume a plausibly high degree of home bias in goods consumption. This follows an extensive theoretical literature that also predicts home asset bias (but arguably our model is much simpler and requires fewer assumptions).

The main finding of Chapter 2 is that home asset bias increases the volatility of the exchange rate in response to productivity shocks. Suppose there is the same fall in productivity as we considered in Chapter 1. In response to this shock, firms decumulate capital because it is less productive and so the supply of the home asset falls at the

new steady state. Because the home asset becomes relatively scarcer at the new steady state, biased investors¹ crowd into the home asset, causing the home exchange rate to appreciate. This occurs until the home exchange rate is so over-valued, relative to its long run equilibrium level, that even biased investors no longer wish to keep accumulating home assets. This is the point where the exchange rate's subsequent depreciation to its long run level lowers the excess return on home assets sufficiently to dissuade even biased investors from holding more home assets.

As in Chapter 1, the long run level of the exchange rate is appreciated after this shock (since the supply of home goods declines). And as we know from Chapter 1, a long run appreciated level and a short run depreciating rate of change together imply an initial overshooting appreciation. The exchange rate thus initially overshoots its long run level after a productivity shock and hence is more volatile under home bias than in the case of perfect substitutability, where the exchange rate experienced mild undershooting after the same shock. Not only is the exchange rate more volatile, it also moves in the opposite direction to that predicted by the UIP condition². We also show that our model overturns the result of a key paper on imperfect asset substitutability by Blanchard, Giavazzi and Sa (2005).

Likewise, the message of *Chapter 3* is that adding a financial sector and financial frictions augments exchange rate volatility beyond the baseline model. The key point is that, in the presence of financial frictions, there is a non-negative risk premium that widens after negative shocks. This increases the burden of adjustment on the exchange

¹Home investors prefer home assets and even foreign investors wish to hold some fixed proportion of their wealth in the home asset.

²In this Chapter, the exchange rate depreciates to its long run level after a negative productivity shock, instead of appreciating. This explains why the excess return on home assets becomes negative after the shock (rather than remaining at zero, as UIP would imply). If investors are biased, no-arbitrage between home and foreign assets does not imply zero excess returns. Rather, because investors are biased, there is excess demand for the home asset (because it is expected to become scarcer) even though the return on home assets falls in response to the shock. And this excess demand is only cleared if the excess return on home assets becomes sufficiently negative.

rate. In this model, we develop a banking sector that borrows from depositors subject to a financial friction in the style of Bernanke, Gertler and Gilchrist (1999). A negative shock worsens the leverage position of the home banking sector (a shock to bank net worth directly causes this; productivity shocks cause banks to make a loss on home assets that indirectly leads to this same outcome). Depositors demand a higher risk premium for lending to home banks because the potential cost of default rises.

This means that the home banking sector must earn a higher spread on its assets above the foreign riskless rate (because depositors have access to both home and foreign riskless assets). This is achieved by the exchange rate appreciating along the adjustment path. A large cumulative per-period appreciation then implies a large initial depreciation. What happens is that depositors withdraw funding from banks and flood to safe-haven riskless assets abroad, leading to financial outflows that cause the initial depreciation. This occurs until the point where the home currency is so under-valued that depositors are indifferent between lending to home banks and saving risklessly overseas. Financial outflows stop, inflows resume and the exchange rate gradually re-appreciates. We find these frictions augment the effect of productivity shocks on the exchange rate. We also find that financial (net worth) shocks have a greater effect on the exchange rate than productivity shocks (given similar-sized effects on other variables). Finally, contrary to the third-generation currency crisis literature, we find that the currency mismatch on bank balance sheets, while important, is not a necessary condition for financial shocks to cause large falls in the currency. This is because increases in the risk premium can occur for reasons unrelated to the mismatch.

Chapter 4 rounds off Chapter 3 with a simple policy experiment. Following Gertler and Karadi (2011) and Cespedes, Chang and Velasco (2012), we consider the effect of policies whereby the government extends emergency loans to the goods-producing sector or to the banking sector. Like these authors, we find that, in the presence of productivity

or net worth shocks, these policies are effective at raising output and investment. The policy of lending to banks may be more effective in this respect, because for each unit of government credit extended to banks, banks (by leveraging up) can extend more than one unit of intermediation to the goods-producing sector. However, lending to banks entails non-trivial costs. This is because it encourages banks to be more highly leveraged. This raises the volatility of consumption and the exchange rate *ceteris paribus*, which is welfare-deteriorating.

2 Possible extensions

The analysis of this thesis suggests that a plausible model for analysing real exchange rate determination and exchange rate jumps may include the following features: the rigid adjustment of capital in the production process; imperfect asset substitutability across borders; financial frictions between borrowers and lenders. Together, these features can generate a substantial degree of real exchange rate volatility. We conclude this thesis with a brief discussion of some other features that may be relevant but have been omitted in our models.

First, we defended our decision to omit a non-tradeable goods sector by appealing to the evidence (Chari, Kehoe and McGrattan, 2002; Engel, 1999) that this is not important in explaining real exchange rate fluctuations. However, this omission is arguably still an over-simplification and a possible extension to all the models in this thesis would be the inclusion of multiple production sectors within each economy.

Second, because we rely heavily on the method of Devereux and Sutherland (2011) (which involves taking linear approximations), our models are solved using standard linear techniques. We offer some justification for our choice of solution method in

section 4.2 of the Introduction. Nonetheless, it would be more accurate to apply non-linear solution methods.

Third, while “routine” monetary policy shocks at the business cycle frequency may not be of interest to us, this does not mean that all monetary policy action is unimportant. For instance, the expected unwinding of the Federal Reserve’s substantial asset purchase programme, which can hardly be considered a typical shock to monetary policy, is broadly interpreted as being responsible for the large falls in emerging market exchange rates since the second half of 2013. Clearly, large unanticipated and unconventional policy action can have a substantial effect that does not wash out until the medium or long run. Even “conventional” policy actions can have a substantial effect if they persist. For instance, a structural change in monetary regimes (for instance, a change to the coefficients in the Taylor rule) may anchor inflation at permanently higher or lower levels and thus affect the terms of trade and the real exchange rate over the long run.

Finally, this thesis has omitted any application of econometrics. An obvious extension would be to test the models against the data. One way to do this would be to try to find long-run cointegrating relationships between capital, portfolio holdings, and the real exchange rate. A vector error-correction model could be estimated with productivity or capital pinning down long run equilibrium levels while financial variables such as risk premia describe short run dynamics. This would be similar to Amano and van Norden’s (1993) VECM analysis for forecasting the Canadian dollar. Another possibility would be to implement a probit model in order to estimate the effect of our variables of interest on the probability of a sudden fall in exchange rates. We leave these questions for future research.